ELECTRICAL TRANSMISSION AND DISTRIBUTION

VOLUME III

SWITCHGEAR: PART I

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SUPER-GENERATING VOLTAGE SWITCHGEAR (LAYOUTS)

BY

W. ANSELM COATES, M I E E , FEL A I E E

SUPER-GENERATING VOLTAGE SWITCHGEAR (APPARATUS)

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GENERATING VOLTAGE SWITCHGEAR

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D C AND LOW TENSION A C SWITCHGEAR

BY

J M GOODALL

ELECTRICAL TRANSMISSION AND DISTRIBUTION

A COMPLETE WORK BY PRACTICAL SPECIALISTS DESCRIBING MODERN PRACTICE IN THE TRANSMISSION AND DISTRIBUTION OF ELECTRICITY SUPPLY

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VOLUME III

SWITCHGEAR: PART I

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PREFACE

THIS volume deals with what is probably one of the most important factors in an electrical supply system

In these days of super-power stations it is essential that the enormous amount of energy involved shall be controlled with safety and absolute certainty

The authors give readers the benefit of their accumulated experience, and deal exhaustively with the subject, the leading points in design being discussed in conjunction with descriptions of the switchboards and apparatus in general use

In the sections on Super-Generating Voltage Switchgear the author, commencing with descriptions of the systems of connections in use, then deals with steelwork, ferro-concrete and timber for supporting the gear, earthing, lightning arresters, busbar selector switches, insulating materials, oil circuit breakers, isolating switches, current transformers, and potential indicators Much valuable information is also given on the layout and general arrangement of switchgear, together with illustrations of typical schemes

The other two sections in the volume deal with such important points as Generator Voltage Switching—Circuit Breaker Capacity—Cubicle, Cellular, and Compound-filled Switchgear—Metal-clad Gear—Application of Fuses—Field, Ammeter, and Voltmeter Switches—Field Rheostats—Instrument Equipment—Traction Switchboards and Rotary Convertor Equipment

The volume will be of the greatest assistance to those concerned both in the design and practical operation of high and low tension switchgear in electrical transmission schemes

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W ANSELM COATES, M I.E E,
FEL A I E E

SECTION IX

SUPER-GENERATING VOLTAGE SWITCHGEAR

(LAYOUTS)

SYSTEMS OF CONNECTIONS

BEFORE the physical arrangement of apparatus can be considered, it is first of all necessary to know the diagram of connections At the generating station end there are three broad possibilities—

1 Parallel the generators and also parallel the transformers at the higher voltage side

2 Connect each generator permanently to its own step-up transformer, and parallel on the higher voltage side only

3 Connect each step-up transformer to its own feeder and parallel only on the generating voltage side

The first-mentioned arrangement is the most flexible for operation, since it makes possible the diversion of generating plant to serve feeders at generating voltage or at the stepped-up pressure at will It involves the greatest expenditure on switchgear, although if the local supply at generating voltage forms an appreciable proportion of the total output, the saving due to installing only the transformer capacity required for transmission at high voltage may well offset the added cost of switchgear

With a system of any great size, with numerous circuits on both voltages, duplicate busbars would almost certainly be required and thus a typical key diagram is as Fig 1

A word as to the duplication of busbars may be in order The additional set of busbars permits the segregation of sections of the plant Thus in Fig 1 it would be quite possible to split apart the whole plant into two entirely separate electrical systems At times such facilities are valuable, in that it becomes possible

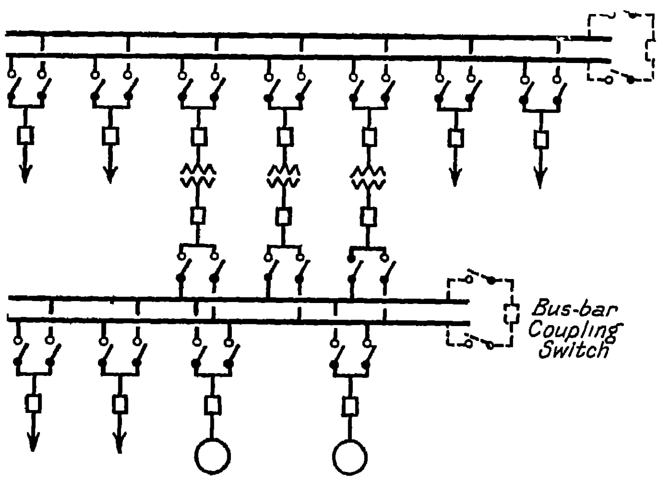


FIG 1 TYPICAL DIAGRAM OF GENERATING STATION WITH DUPLICATE BUSBARS ON HIGH- AND LOW-VOLTAGE SIDES

to work sections at different voltages, perhaps to take care of extra heavy loading, or because it is desired to apply pressure gradually to apparatus after repair

A scheme arranged as shown in full lines only would be of doubtful value, since if the whole plant were operating in parallel it would be a difficult and dangerous job to split it apart, and, once separated, it would be impossible to bring into parallel again without shutting down one part It is necessary to add the busbar coupling or paralleling switch, shown in dotted

lines A little thought will reveal how this can be used as the last thing to be opened or closed when splitting or paralleling

Provided busbar paralleling means are available, a duplicate set of busbars makes it possible to connect a generator to a dead line, charge it up to working potential, and then be connected in parallel with plant already transmitting considerable load over other feeder lines on the higher voltage side

In very elaborate layouts a circuit breaker per busbar per circuit may be used, but it is very rare that the extra cost is warranted

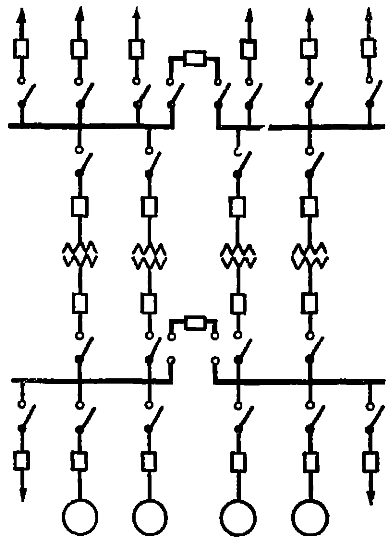


FIG 2 TYPICAL DIAGRAM OF GENERATING STATION WITH SINGLE BUSBARS ON HIGH AND LOW-VOLTAGE SIDES

It often happens that there is no necessity for simultaneous operation at different voltages and that the points supplied can be fed by more than one feeder A single set of busbars would meet the daily operating requirements, and if the layout be made (as in Fig 2) to include the bus sectioning switch shown in the centre of each bus, it is still possible to segregate a portion of the plant during progress of maintenance work

Apart from the saving in capital spent in transformers

if there is much local load, the practice of switching each transformer independently presents certain other minor advantages Only the actual transformer capacity required at any time need be kept in circuit, so that losses are a minimum The size of transformer units may be fixed to secure greatest buying economy, since the capacity of the equipment does not enter the

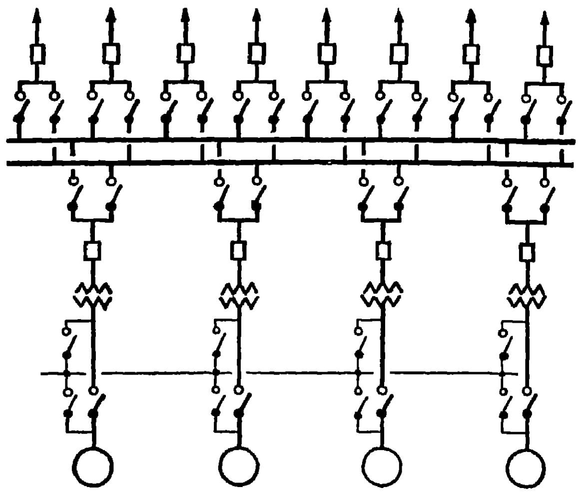


FIG 3 TYPICAL DIAGRAM SHOWING GENERATORS AND TRANSFORMERS SWITCHED AS SINGLE UNITS

question Finally, in the event of transformer breakdown, the protective gear operates to cut out the transformer only, and no other part of the plant is disconnected

The second possible arrangement indicated might work out somewhat as in Fig 3 in a simple case The practice of working each generator with its transformer as a unit has been followed frequently in the larger

power stations in this country In these cases, however, the higher voltage has never exceeded 33 kV, and the bus system has usually been subdivided and reactors have been introduced after the manner familiar on generating voltage switchboards

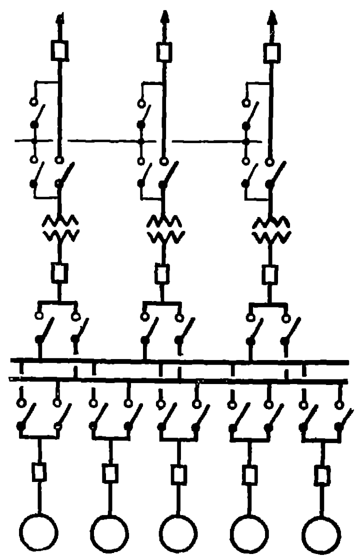


FIG 4 TYPICAL DIAGRAM SHOWING TRANSFORMERS AND LINES SWITCHED AS SINGLE UNITS

Each transformer is of the same capacity as its generator, and the only switchgear on generating voltage is a transfer bus with selector isolating switches (shown in lighter lines), by means of which it is possible to work any generator with any transformer in the event of breakdown Local supply is generally arranged through step-down transformers from the higher voltage busbars

This switching scheme shows to best commercial advantage when the generators are few and the high voltage feeders many, showing up particularly well in large capacity stations, since heavy current, large rupturing capacity circuit breakers, and their associated switchgear are very expensive

The Fig 4 may be considered representative of the third scheme By a line of argument similar to that just used, switching feeder and transformer as a unit is most economical when there are many generators

and feeders at generating voltage, with but few feeders at super-generating pressures If the super-generating voltage feeders are all radial and not paralleled at their far ends, it is not essential to equip them with circuit breakers As an engineering scheme it is not very sound, since the capital expenditure and daily running costs of the transformers are higher than need be Further, it must be borne in mind that with overhead transmission, the majority of service interruptions are due to line troubles On all such occasions the transformer also would be cut off and the system exposed unnecessarily to the risk of heavy current rush accompanying re-connection

In the days when increasing operating pressure meant greater risk of trouble with the switchgear, this scheme was adopted rather freely These days are well over, and it is no longer considered good practice to control circuits in this way

Although the foregoing remarks have been made in direct relation to generating station equipments, the principles involved hold good in substation work In the majority of substations, however, transformers are paralleled and have circuit breakers on both sides, duplicate busbars, section switches and bus coupling switches being employed according to the importance of the service to be rendered

It is presumed that the reader is generally familiar with the usual systems of distribution employed—radial feeders, paralleled feeders, and ring mains—and these will not be treated in detail Attention is drawn however, to the switching arrangement being used at substations on the ring mains on the British 132 kV grid system, since this is a novel one

In the left-hand diagram of Fig 5 is shown the conventional arrangement of switchgear to control a substation which has two incoming feeders and two

paralleled transformers, and in which balanced voltage and circulating current protective gear are employed. The right-hand diagram indicates the scheme which is being adopted for the British "grid," using the same

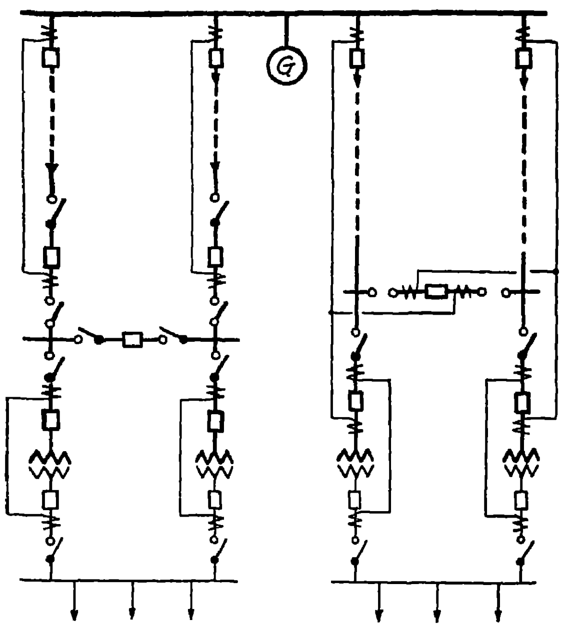


FIG 5 POSSIBLE SWITCH ARRANGEMENTS IN SUBSTATIONS WITH DUPLICATE INCOMING FEEDERS

types of protection The idea is due to Mr J R Beard, and was first published in his inaugural address as Chairman of the Newcastle local section I E E, in 1921

In the usual arrangement, each individual incoming feeder cable is furnished with its own protective gear,

operating on the breakers at its extremities, while the transformer circulating current protective devices open the high- and low-tension breakers In Mr Beard's scheme the protective transformer at the supply end is balanced against two others at the substation end, and, in the event of feeder trouble, two of the three breakers in the substation would operate, leaving one power transformer connected to the healthy feeder The well-known device of overlapping zones of protection is resorted to so as to trip all parts of the switchgear inside In the left-hand portion of the diagram it will be seen that the busbar and higher-voltage section switch are not protected in any way

Two quite expensive circuit breakers are saved in each substation in this way The scheme does not lend itself to extension quite so easily as the more conventional arrangement, perhaps, but, as will be shown later, it is capable of making a very desirable substation arrangement in those cases where future requirements are fairly well defined from the inception

Concluding this section, it is impossible to do better than repeat the advice given in the address by Mr Beard just cited When the preliminary scheme for any system has been completed, go over it switch by switch, and consider if there is any way by which it can be dispensed with without impairing operation Many switching schemes are unnecessarily elaborate

To this the writer would add, consider the diagram not only station by station, but take the system as a whole Imagine what would have to be done if the plant capacity were increased by at least twice as much as at present seems reasonable to expect See to it that the designs first adopted are capable of extension or modification to suit these increased duties, without disproportionate expenditure and inconvenience when the time comes to make the change

CONSTRUCTIONAL METHODS

Switching apparatus at super-generating voltage is only rarely placed under cover in these days, it having been found that the extra cost of weatherproofing apparatus is as nothing compared with the cost of the buildings needed to enclose apparatus working at the higher pressures, where the clearances between conductors and to earth are very great In the present section the subject is treated as though apparatus would be outdoors as a matter of course, but, where necessary, indications are given of practical changes which are permissible if open type construction is used indoors The latter is occasionally resorted to in such countries as Northern Canada and in Russia, where the intense cold of winter makes maintenance very troublesome with outdoor equipment Metal-clad apparatus, now widely used up to 33 kV, is treated separately later

Steelwork Structures. In most cases steel structures are employed to support apparatus such as busbars or isolating switches, which it is desired to have on a higher level than the rest of the equipment On very high-voltage work it is not uncommon to have the highest apparatus 50 to 60 ft above ground, and for the supporting columns to be spaced apart by 30 to 40 ft Lattice steel girder construction is obviously the only thing to use in such cases

In designing these structures, allowance is made for the usual ice loading and side-wind conditions prevalent in the district of installation, but in addition there must be taken into account—

1 The dead weight of all supported apparatus

2 The transverse pull due to conductors strained from point to point within the structure, or to overhead feeder lines dead-ended on the outside girders

3 The live loads due to any men who may be upon the structure during erection or subsequent maintenance

4 Loads imposed during erection or maintenance by fastening tackle to the structure when lifting apparatus which may be beneath

The last two factors are very commonly overlooked, and have been the cause of more than one mysteriously deformed structure

As a rule steel sections are specified to have not less than $\frac{3}{8}$ in web thickness and to be hot galvanized after all cutting, drilling, etc , is finished Because of the difficulty in galvanizing bulky parts, the elements are almost invariably bolted together, and not riveted Bolts and nuts present a problem, as there is no method of weatherproofing such things which will withstand the atmospheric conditions in some industrial areas Probably the best method is to cut the threads extra deep at first, hot galvanize, and then run through standard size tap or die This will protect a great part of the surface When assembling on the job the threads should be liberally greased

Galvanizing should be used invariably anywhere near live conductors, but it is permissible to save money by using a bitumastic paint on the black steel on those parts of a structure, such as the lower portions of columns, where painters' lives would not be endangered during annual or bi-annual repainting The life of galvanizing is rather indefinite A well-done job may easily last twenty years or more, while an indifferently galvanized surface might reveal signs of rust inside a year in bad localities In nearly every case, however, the completely galvanized job will be the cheaper in the long run

On the Continent zinc is deposited on the completed structure by means of the blowpipe pistol in

quite a number of cases When expertly done, a uniform coating 0 004 in thick placed in this way will stand up to all the usual tests applied to hot galvanizing The great difficulty is to test the actual work on a big structure, and it undoubtedly requires considerable skill to use this device successfully

In cases where the height of columns and length of beams is of the order of 20 ft or less, it is frequently possible to use as members simple lengths of rolled " I " and angle sections, or even heavy gauge steel tubing The latter, when fastened with clamps, is extremely easy to erect and has a pleasingly light appearance as compared with the " steel forest " effect given by so many lattice work structures

When switching apparatus is located indoors, the walls and roof naturally afford support for the major part For remaining items pipework supports almost always suffice, since the loading conditions are much less severe than with outdoor equipments

It is fair to say that quite 50 per cent of the structures built are heavier than necessary because designers adhere solely to the use of vertical and horizontal members, without using cross braces, spanning the main bays, to give rigidity Similarly, it is conventional for all members of lattice structures to be square or rectangular in cross-section and parallel-sided Material economy could be effected by using columns of triangular section, tapering towards the top, and beams the ends of which are of reduced depth

With all steel structures, care is necessary to avoid pockets in which water can collect Unavoidable pockets should have drainage holes in the lowest part, and on pipe structures the ends of each must be properly plugged or blanked off

A further detail often overlooked is the provision of means of safe and easy access to apparatus Climbing

steps should be furnished up some columns, and where the beams are any great height, permanent or removable handrails right along them are desirable for use during erection and maintenance.

Erection of lattice columns is facilitated if they are bolted to stubs built into the foundation blocks. The columns can then be built on the ground and hoisted into position, using the stub angles as hinge blocks. There is no time wasted while concrete sets before all the beams are bolted in place, and no bother with temporary guying. It will only pay to grout in the footings of vertical members if these are short lengths of rolled section or tubes.

Attempts have been made to support apparatus by wire ropes, strained off tubular columns, following the methods used for tramway overhead work. These have worked out badly because the whole arrangement lacks rigidity, and the relatively great weight of individual items has resulted in unsightly sagging in the supporting wires.

Ferro-concrete Structures. It was remarked above that galvanizing cannot be relied upon in our worst industrial areas, where the atmosphere is often laden with every imaginable corrosive agent. Bitumastic paints are equally limited in value in these places. This has led to the employment of ferro-concrete as a means of support, since in this the steel is buried out of harm's way. The material is, of course, more bulky than an all-steel structure of like strength, and there are distinct limitations to the beam span which can be used in practice. As will be seen from examples illustrated later, however, quite elegant structures can be made to substitute these, which otherwise might be built of single rolled steel sections. (See page 509.)

The most recent application of ferro-concrete is for the supporting plinths used in single plane switchgear

layouts, typified by the "A 1" class substation being standardized by the Central Electricity Board (See pages 509 and 512)

Timber Structures. In countries where suitable material is abundant, wood is often used for structural frameworks, even for quite high-voltage work Its use is decreasing, partly because of its short life, but chiefly because almost everywhere the cost has risen to a point where steel is as cheap Wood poles are widely used for transmission line construction, often untreated if used in the place of growth, although in England and most European countries impregnation with creosote or other preservative is usual It follows that the switching apparatus for less important services from such lines, if light enough, is mounted on wood pole structures

Apparatus Seatings on Structures. Care is necessary in arranging to mount equipment on structures, firstly to avoid weakening the member to which attachment is being made, and, secondly, to avoid imposing strains tending to twist it With a view to maintaining unimpaired strength, some engineers utilize clamp attachment only On tubular frames this is the only practical method, but with lattice or rolled section structures a limited amount of drilling is generally permissible

When main line conductors are dead-ended on the structure and are strained up to any appreciable pull, an anchoring plate or channel section should be fixed right across the width of the lattice member, and the insulated eyebolt fastened centrally thereto, so that the pull is equally distributed on both sides of the lattice Short lengths may be dead-ended on any convenient part of the lattice work

Fuses and isolating switches are usually mounted transversely on or under beams, and their bases may overhang some distance at each side If the weights

overhanging are balanced at all times no special precaution is needed This cannot be the case with isolators, however, unless they are of the type having a central rotating insulator A bracing bar from the extremities of the base to the opposite side of the beam becomes necessary with other designs

One of the most common mistakes is to mount single pole hook-stick operated isolators too high up. Indoors it is possible to handle a 20 ft pole, but in a strong wind a very muscular man is needed to negotiate one half that length Much help can be given by providing intelligently designed projections on the isolator blades A mere hole through the blade, such as is used for lower voltage work, is utterly useless in the open

Although the girder work may be properly designed, it has to be borne in mind that it does deflect under load, and that the deflection when men are upon it erecting apparatus will be greater than when they have returned to ground Due allowance for this is necessary in erecting the coupling rods of triple pole isolators, driving mechanisms and the like Flexible couplings are sometimes used between adjacent poles when they are widely spaced

Conductors. Current-carrying capacity is generally a minor consideration in designing the conductors for a high-voltage substation Mechanical strength is usually the controlling factor, while on the highest pressures the size is determined by corona limitations Round or stranded conductors are used invariably The objection to corona is not that of energy loss, which in a switching station would be unimportant, but that streamers striking at the surface of a dielectric may in time result in its breakdown For this reason alone sharp edges should be avoided in the design of high-pressure apparatus as far as ever possible

For indoor work, copper tube or gas pipe makes the neatest job of the connections Joints are made with screwed couplings or tees, or by solid inserts which are pinned into the ends, and soldered there Conductors made in this way are really only semi-rigid and need frequent support For example, a $1\frac{1}{2}$ in diameter tube, with $\frac{1}{8}$ in wall, supported on 20 ft centres, would have a sag of 4 in if of copper, or about $2\frac{1}{8}$ in if of gas pipe. Because of this, tubular conductors are only exposed to the added wind and ice loading of outdoor work when quite adequate support can be given

Stranded conductors, strained up like a transmission line, are used for most outdoor work Solid copper, aluminium, aluminium-steel, or the recently patented Thos Bolton's tubular copper stranded cables are all used in this way Clamp grips are used at the ends and at all branch connections It is essential to calculate the sags under extreme conditions for all items, not only to ensure maintenance of proper clearance, but to facilitate erection In many cases it is hardly possible to get at, for example, the middle of a strained buswire with a view to fixing a branching conductor The easiest job is to lay out the buswire on the ground, make all tees at the proper places and hoist the complete thing into place

In deciding upon the position of jumpers, branch conductors, etc , thought must be given to the extent of movement which might occur, and anchoring insulators used if needed to prevent danger There is no necessity to strain from both ends every conductor employed in the connection system, but where a lead, partly free at one end (e g tapped from the middle of another strained conductor), terminates on a rigid post insulator, or bushing, care is necessary to ensure that movement in the wind will not throw too great a strain on such terminal

Clearances. There are no existing British standards governing the clearances which should be used between conductors and between conductors and earth on pressures over 33 kV, and the practice in other lands on very high voltages is widely variable In general it may be taken that the clearances indicated in Fig 6

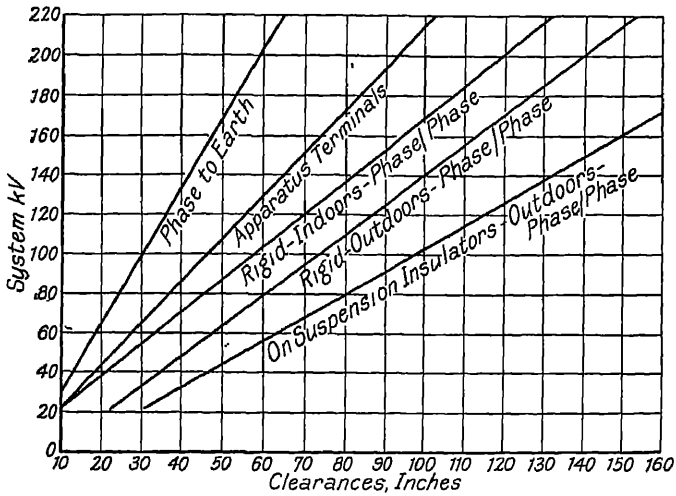


FIG 6 MINIMUM CONDUCTOR CLEARANCES

would be accepted as permissible minima when the conductor is practically rigid, but that most engineers would allow up to 50 per cent greater figures, especially phase-to-phase, provided it were possible without much extra expense In using these dimensions to fix the location of apparatus, strain, post, or suspension insulators, full allowance must be made for sags The weight of strain units plays a big part in determining the ultimate sag of short conductors, the usual ice and wind allowances must be made, and the fact that

irregularly loaded conductors being side by side may not swing in synchronism must be taken into account.

On the lower pressures, when conductors are to run vertically, it is customary to support them by pin insulators which are mounted with their axis at 45 deg. When this is done, the distance from the outer edge of the largest shed to earthed metal should never be less than that from the pin to the inside edge of the smallest shed, even though this means greatly exceeding the figures in Fig 6 above

It is better to avoid passing conductors in different circuits one above the other, because of the risk attendant upon the failure of an insulator at the lower level The attendant arc is quite uncontrolled, except by a possible system neutral earthing resistance, and in a favourable wind it may rise many feet When transformers or circuit breakers are located beneath conductors which may be alive from some other direction, ample clearance is necessary above them to permit complete removal of bushings

Still more important is it that air break switches intended to break current, and lightning arrester horns, should have ample clearance Every effort should be made to keep such things right at the top of all structures, where there is no chance of the arc being blown into adjacent metal, but in any case the limits indicated in Fig 7 should be regarded as absolute minima

Earthing. The structural work in an outdoor substation in itself forms quite a useful protection against lightning damaging the apparatus, especially if the latter is all below the level of the highest steel members This furnishes an added reason why the usual practice of bonding together all metal not alive should be carried out carefully

It is desirable to run a copper earth bus not smaller than 1/16 sq in section along each main column and

girder Mechanical cleats at intervals will give sufficient electrical contact, but the bases of isolators, switch tanks, etc , should each be connected independently to the earth bar by copper conductors The earth bus should be connected directly to the earth at not less

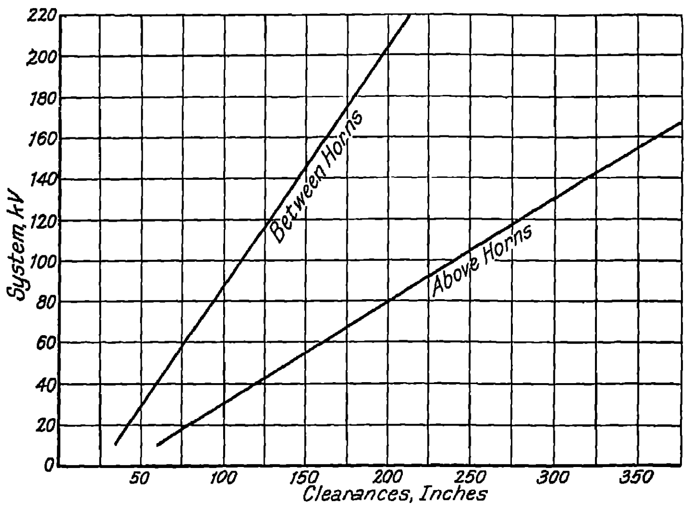


FIG 7 MINIMUM CLEARANCES FOR ARCS IN AIR

than two separate points, usually the extremities of the switch yard.

Individual means of earthing should be provided for transformer neutrals and for lightning arresters, and such means should be as close as possible to their apparatus Some operators tie together their neutral earthing systems with the general earth bus This is not good, because when current passes to earth it frequently dries out the earth surrounding the plates or pipes and thus increases considerably the contact resistance The neutral point of a system is earthed solely to gain

certain operating advantages, and it is not a vital matter if these are lost temporarily, but the structure, tanks, frames, etc , are earthed for the safety of those working among them, and no chance must be taken

In the case of lightning arresters, the risk of drying out is much greater as the currents to ground are far heavier Moreover, it is absolutely essential to place the earthing device right at the arrester, so as to avoid bends in the earth conductors

The actual connection to earth may be made by means of a special copper or cast iron earth plate, buried in a bed of coke below the permanent water level Another very handy method is to drive two or more 1½ in steel pipes into the ground and connect into their projecting ends This scheme has the great advantage that it is possible to check up the contact resistance obtained while the work proceeds, and to add more pipes till the desired ohmic resistance is obtained A buried plate job must be completed before a check is possible Where permanently moist ground cannot be ensured, a pipe should be taken to the surface so that water can be supplied when necessary

The value of contact resistance desired is usually not over 2 ohms for neutral connections and for structural earthing, but for lightning arresters up to 15 to 20 ohms is permissible in view of the very high potential obtaining when current passes through this earth connection Periodical checks are essential to make certain that contact is being maintained For this purpose the several plates around the plant are disconnected one by one, and the resistance measured between the isolated one and all the others in parallel

In very rocky country the problem of establishing connection with the general body of earth is often extremely difficult Erecting engineers are well advised to check up the resistance between their earthing

devices and the plates in neighbouring stations, as conducting pockets of ground, almost insulated from the mass, are not unknown

In other places there is no possibility of making earth contact at all, and it is necessary to run insulated earth lines to a more or less remote point where an earth can be made If this is within, say, 400 yd of the switching station, it is best to place arresters there, so that a straight earth run is obtained If the distance is much greater, the wisest course is to spend the money on insulation and on making an effective bonded structure around the switchgear, connected to the line overhead wire, omitting lightning arresters altogether

In such places there may be a considerable fall of potential within a man's stride over the ground Probably the safest means of meeting the difficulty is to place large steel plates on the ground under and around all equipment, adjacent plates touching, so that in effect there is a continuous metal floor

OUTDOOR LAYOUTS

One of the great advantages of placing switching apparatus in the open is the relative independence of boundaries and levels The cubic space occupied may be greater than if the gear were under cover, but there is rarely any limit to upward extension When selecting the site for an outdoor station it is usually best to treat as the most important factor the direction from which feeder lines will approach, and their relative disposition Pull-off insulators on the switch structure are in the horizontal plane, while the lines may be disposed horizontally, vertically, or in any triangular formation between If the planes must be changed, the pull-off insulators must be spaced out considerably, as otherwise line-to-line clearances will be reduced below standard in the middle of the final span Similar spacing

out is needed if the line approach is anything but normal to the switchgear structure, as will easily be seen

Transport facilities probably deserve second place in importance, more especially where transformer stations are to be designed Circuit breakers may be heavy and clumsy to handle, but once in place need never be moved Most undertakings like to be able to give transformers a workshop overhaul every few years

If a reasonable roadway is possible, it may be assumed that sufficiently firm column foundations also can be made The comments on earth connections in the previous heading will point to the possibility of finding rather too solid foundations—on a granite bed, for example—since this would militate against making good earths at the right places

Quite an interesting demonstration of independence of ground contour is furnished by Figs 8, 9, and 10, showing the switchgear for 66 kV at the Mulungushi Power Station in Rhodesia, built by Metropolitan-Vickers Co As will be seen, the gear is located on a hillside with a slope of about 1 in 2, relatively simple terracing being sufficient to take the several items of equipment The expenditure on insulators and conductors is, perhaps, rather higher than would have been the case on level ground To offset this, however, clever advantage has been taken of the rising levels to place operating platforms facing all isolating switches, permitting the use of inexpensive, hook-stick operated links instead of the more costly gang-operated form almost inevitable in more conventional arrangements

Other notable features of this station, to be seen from Fig 8, are the use of stub-buses—short, intermediate connections—both above and below the busbars, and the employment of suspension isolating switches in the upper set of these stub-buses When avoidable, conductors are better not strung over both

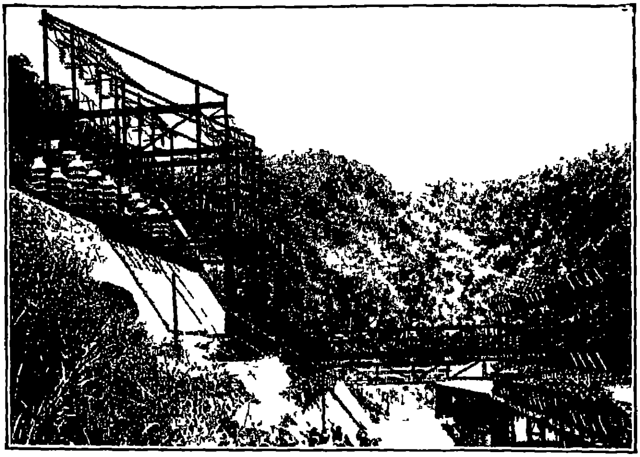


Fig 9 General View of Upper Part of Switchgear

Fig 10 General View of Lower Part of Switchgear, Showing Transformers

sets of busbars in this way, but in this case the ground contour makes the arrangement essential, and the short length makes practically certain that no breakage could occur, and thus short-circuit both main busbars

The auto-valve lightning arresters on the extreme right hand are ideally located, conductors coming short and straight directly from the overhead lines and with the choke coils so placed that there are no intermediate insulators to flash over

In many cases, when alternative schemes have been laid out, it has been demonstrated that there is very little difference in total cost between outdoor schemes laid out (*a*) irrespective of area covered, the aim being to reduce height of structure, (*b*) irrespective of height, with the object of minimizing ground space, or (*c*) with the gear on a power house roof, where ground cost may be considered as zero, but the roof must be strengthened to carry the extra load This latter arrangement is often resorted to in rough, rocky country, where the cost of clearing a site would be great

A series of illustrations, representative of the work of British manufacturers, and showing variants of the several methods of construction, has been selected These are set out in the order of structural cost and elaboration, for lack of any more definite manner of grouping

In Figs 11 and 12 is shown the 66 kV equipment built by Messrs A Reyrolle & Co , and installed at Stoney Cut, Co Durham, about half-way between the North Tees and Dunston Power Stations of the Newcastle-on-Tyne Electricity Supply Co This was the first outdoor switchgear at this pressure in Great Britain The switchgear controls a tee-off from the main tie-line between the power stations and comprises three circuit breakers, two in the main line and one in the branch circuit, controlling the high side of a 66,000/20,000

FIG 11 66 kV SWITCHGEAR (BUSBAR SIDE)

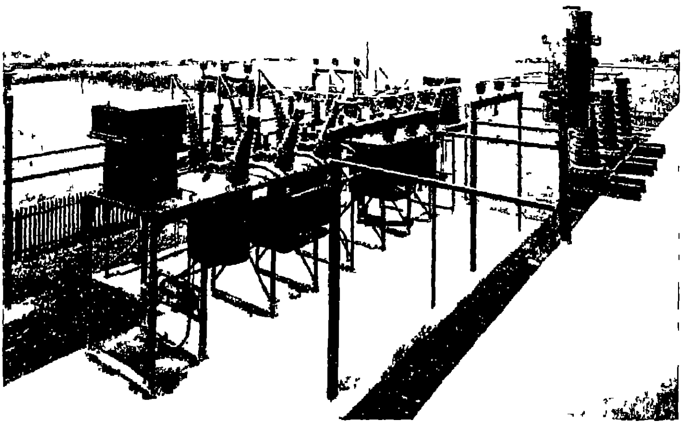


FIG 12 66 kV SWITCHGEAR (SUBSTATION SIDE)

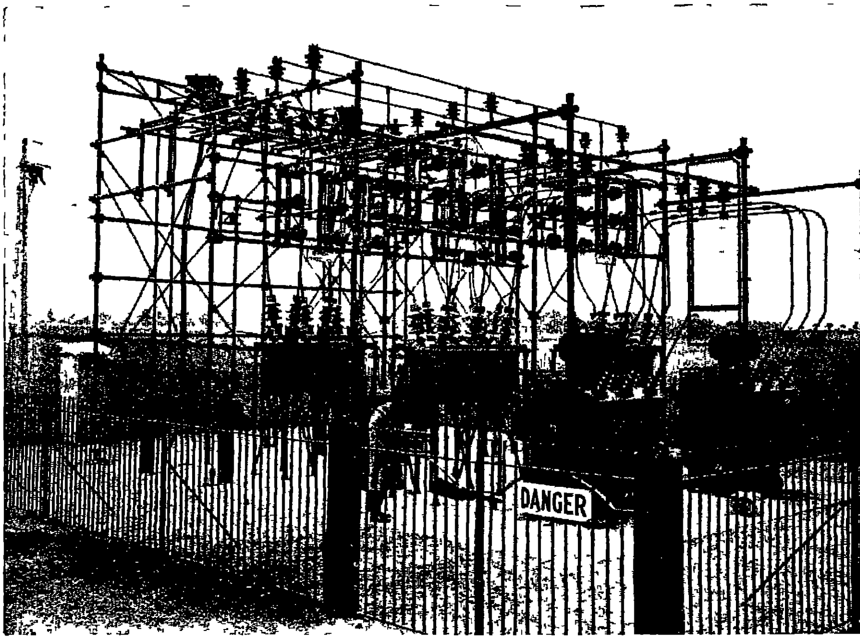


FIG 13 FERGUSON PAILIN 33 kV SWITCHGEAR WITH PIPE FRAMEWORK

volts transformer supplying the main distribution network

Attention is drawn to the manner in which steelwork and insulators have been reduced by using carriage type isolators, the tracks for which are on the same level as the circuit breaker tops with the circuit-breaker condenser terminals acting as isolating switch posts In Fig 11 the isolators are shown closed, and in Fig 12 they may be seen on the far side of the circuit-breakers in the open position

The latter view also gives some idea of the circuit-breaker design The operating gear is motor-driven, the rotary shaft passing from pole to pole above the top frames Rack and pinion gear is used to lift the contacts The vent pipes from each pole, entering a common header pipe at one side, are also apparent

Fig 13 is a good typical example of the class of work which can be carried out with a pipe structure, the station being that at Buntingford, on the 33 kV system of the North Metropolitan Power Supply Co The pipes are merely held one to the other by bolted clamps, but it will be observed that the structure is sufficiently rigid to carry gang-operated isolators, operated through a torsion shaft, lever and pull rods, the spacing and alignment of which must not change at all

The busbars and conductors are made stiff and self-supporting, a relatively easy matter with the short runs necessary on the lower voltages Attention is also drawn to the way in which the feeder line is dead-ended on the lattice mast in the extreme left of the picture, a cable being run thence to a trifurcating box carried on the top of the switch structure It has been demonstrated practically, that the capacity of such a relatively short length of cable serves a very useful purpose in dissipating over-voltage surges, serving the same

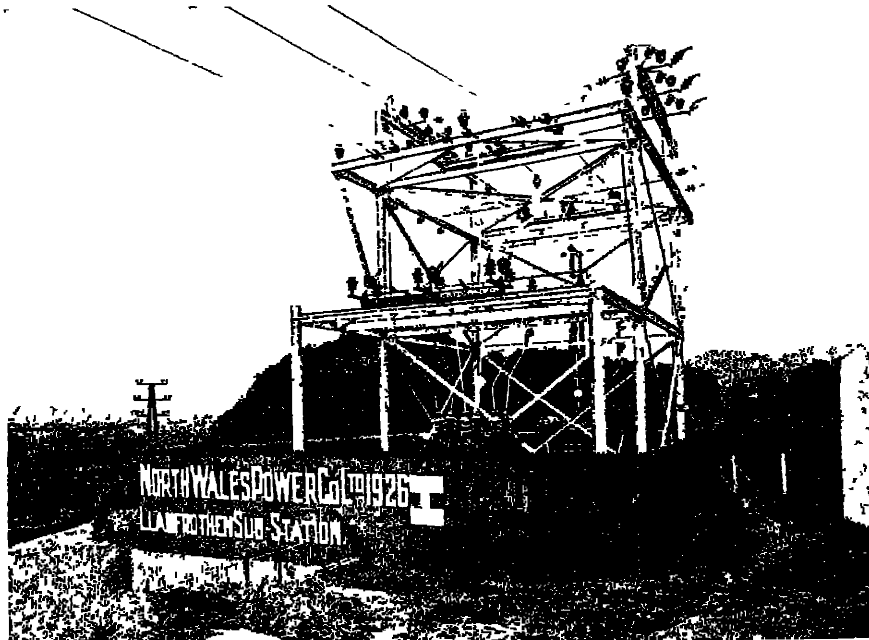


Fig 14 A Ferguson Pailin Substation

function as the batteries of glass condensers frequently used on Continental installations

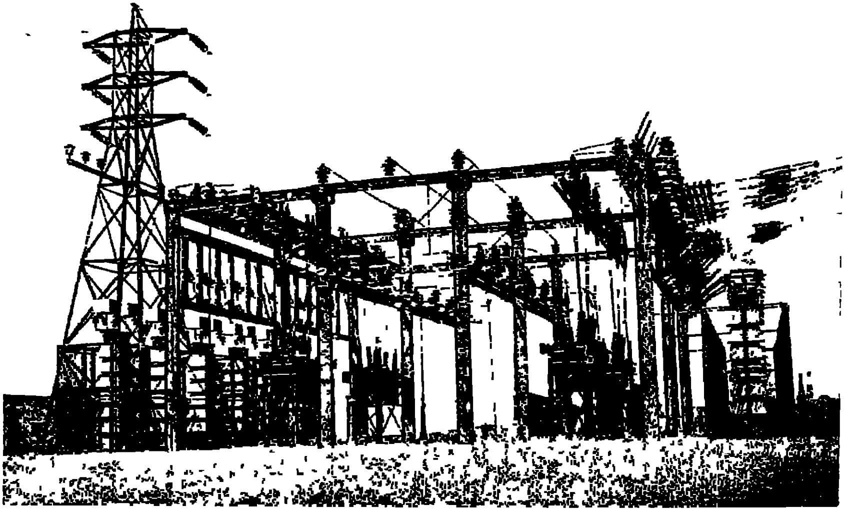
A small tee-off transformer station constructed with galvanized steel sections is shown in Fig 14 The horn-break switches at the top of the framework are in the main line run, tappings being taken from the stub-bus connecting them down to the circuit breaker which controls the transformer primary Both high- and low-tension feeder lines are dead-ended on this structure

White discs seen in the conductor run, just above the circuit-breaker and transformer, are ammeters mounted directly on the conductors This is a not unusual practice on indoor work of Continental design, but is something of a novelty on outdoor stations

An example of the British Thomson-Houston Co 's work, employing heavy rolled section framework, is shown in Fig 15 In this design the stiffness of the columns alone is relied upon to give rigidity, without need for any cross-bracings, even though the outgoing feeder lines are strained off on the structure The suspension type choke coils in these lines should be noted This form of choke coil is very useful, not only because no supporting frame is needed, but also because it avoids placing insulators in a position where they are bound to be subjected to any over-potentials which may occur

The feeders on this side are unusual also in being run in pairs for split-conductor protection This presents little difficulty from the switchgear standpoint, but it is usually quite troublesome to string the twin wires so as to prevent accidental contact

The arresters are of the oxide film type, and are fitted with twin horn-gaps, connected to the two parts of each phase conductor, but paralleled on the other side



Burmah Oil Co)

FIG 15 B T -H 33 kV RECEIVING STATION

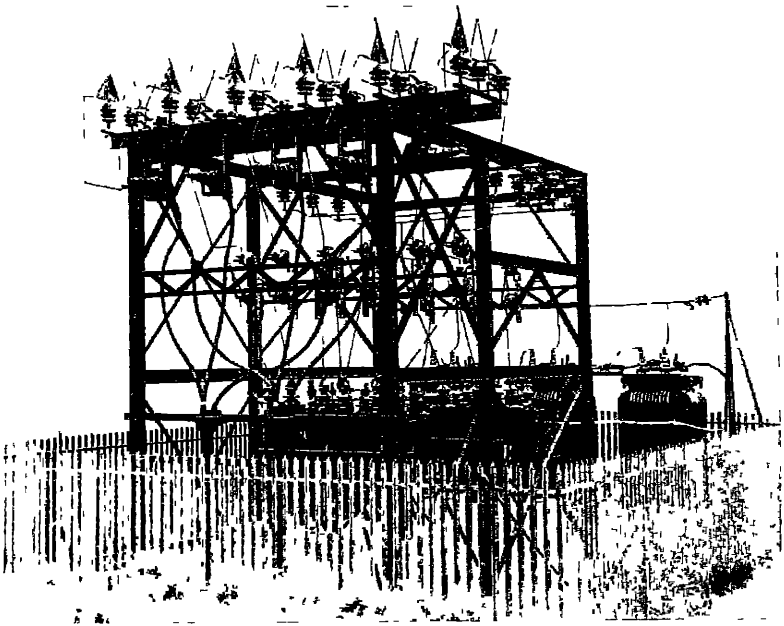


FIG 16 METROPOLITAN-VICKERS 33 kV SUBSTATION

where they are associated with a standard three-phase lightning arrester equipment

The small transformer station shown in Fig 16 is noteworthy by reason of the employment of Burke type arresters in conjunction with the cable feeders previously referred to It will be seen that these cables reach the substation as three-core, are split in a branching box, and the insulated single-core tails are then taken to pot-heads, located immediately below the arresters

In a previous page the limited field in which ferro-concrete could be employed economically was mentioned The equipment shown in Figs 17 and 18, which was built by Messrs Ferguson Pailin, Ltd , is just about the upper limit If larger bay centres were required, the necessary extra depth of beam would bring the structure cost well above that for galvanized steel It has to be recognized that even with a concrete main structure, there is still considerable exposed ironwork in the form of isolator bases, switch tanks and frames, etc , all of which will ultimately have to be painted if galvanizing proves insufficient protection

Regarding the example illustrated, apart from the structure itself, the only somewhat unusual feature is the incorporation of wound primary current transformers and of potential transformers for metering purposes The former will be seen in the upper central foreground (Fig 18) and the latter just inside the right-hand part of the structure in Fig 17

Greater novelty attaches to the design of the Central Electricity Board's three-switch substations now being built by Messrs Metropolitan-Vickers and the British Thomson-Houston Co , a model of which is shown in Fig 19 The diagram of connections is that shown in Fig 5 In this case apparatus has been kept on one plane as far as possible, the isolators being placed

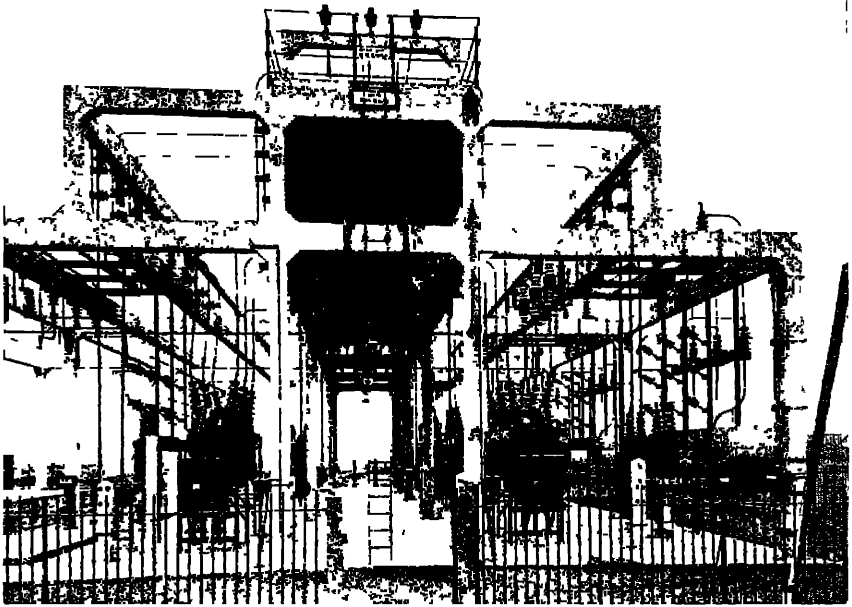


Fig 17 Ferguson Pailin 44 kV Switchyard

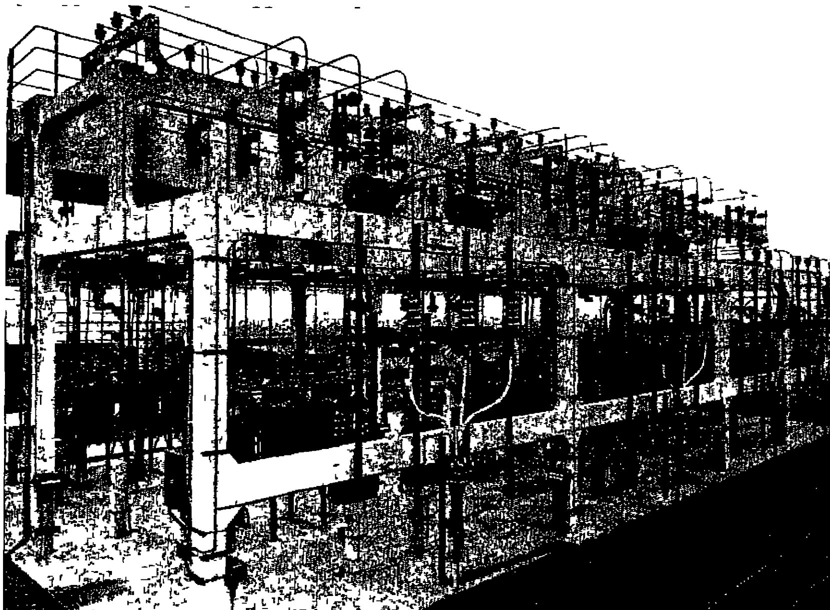


FIG 18 FERGUSON PAILIN 44 kV SWITCHYARD

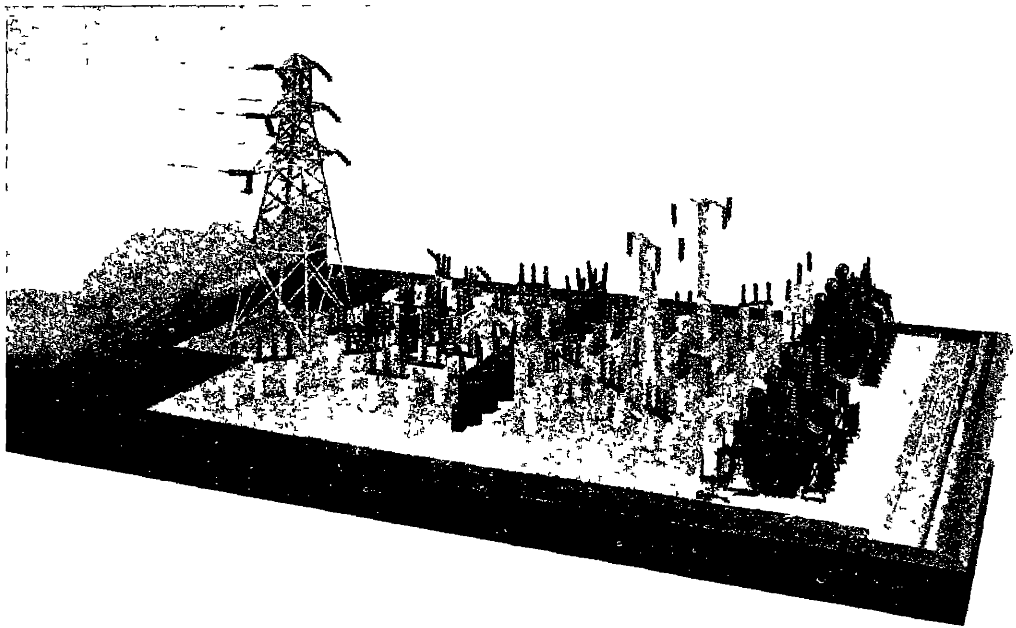


Fig 19 Model of 132 kV Substation for Central Electricity Board

alongside, rather than above, their circuit breakers The only departure from the single plane is at the transformer connections, which are raised on concrete gibbets to clear the conductors tying the two circuits in parallel The concrete posts merely serve to raise insulators sufficiently high to prevent danger to men walking through the yard The natural assumption is that such a layout must occupy an enormous ground space It is, of course, greater than if a conventional steelwork arrangement were used, but the cost of the completed work will be much lower

Somewhat similar arrangements have been used both on the Pacific coast of the United States and in Germany The former is on 220 kV and the latter on 100 kV The reduction in overall costs is more marked as the system pressure is raised, because of the greater clearances in air which must be allowed for

Fig 20 shows an equipment supplied by Messrs A Reyrolle & Co to the New Zealand Government, for use at tee-off substations on the Mangahao 110 kV system As on lower voltages, the circuit breaker is motor-operated through a shaft carrying pinions which engage with racks associated with the moving contacts The illustration shows well the proper application of different types of isolating switch Hook-stick operated switches, mounted low and accessibly, serve the circuit breaker, while on the top of the structure, mechanically remote controlled, gang-operated switches are used for by-pass purposes

The Witbank power station on the 132 kV system of the Victoria Falls and Transvaal Power Co , built by Metropolitan-Vickers Co , is taken as representative of the largest class of outdoor station (See Figs 21 and 22) The lattice structure shown is 52 ft high, main bay centres being 38 × 61 ft Attention is drawn to the lattice braces right across the end bays, to stiffen up the whole structure

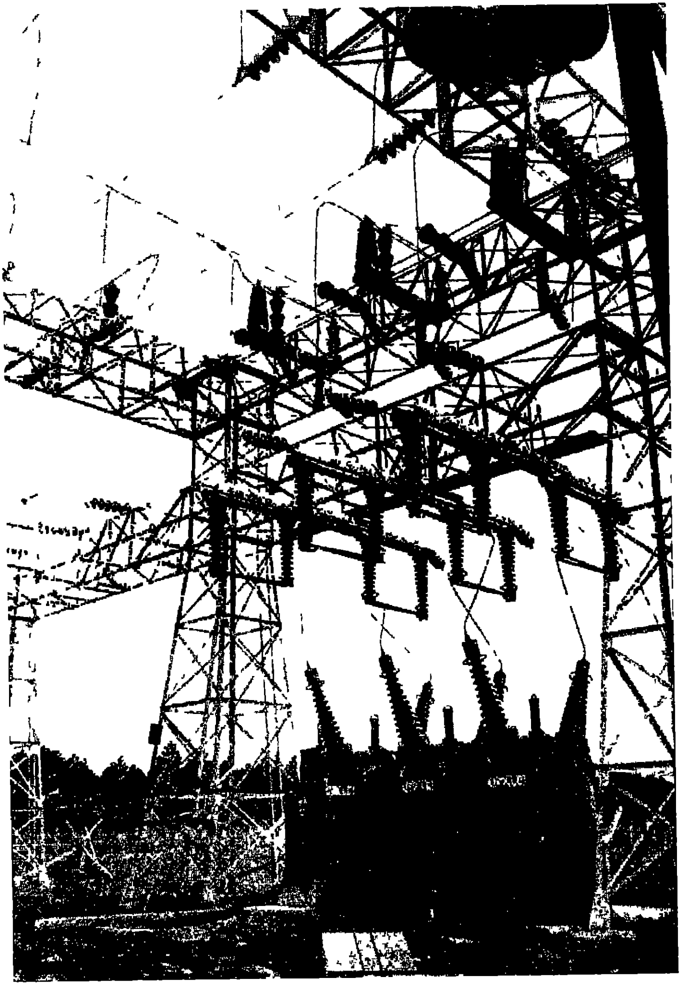


FIG 20 REYROLLE 110 kV EQUIPMENT

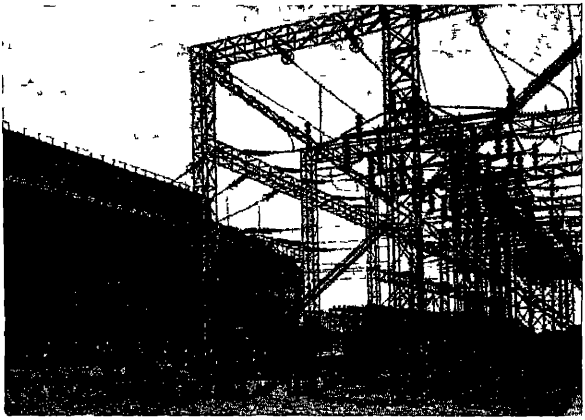


FIG 21 VICTORIA FALLS AND TRANSVAAL POWER CO , WITBANK STATION

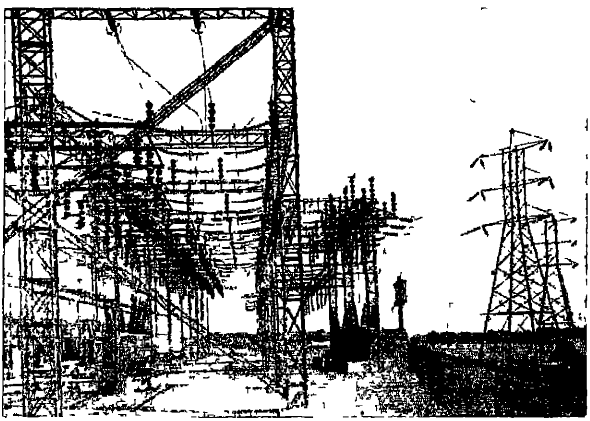


FIG 22 VICTORIA FALLS AND TRANSVAAL POWER CO , WITBANK STATION

The height of the steelwork was kept down by a slight departure from usual practice, in that the busbars were strained off between the top beams at the extreme ends, and supported on posts at intermediate points, as shown in greater detail in Fig 23 As a rule, these intermediate girders would have been taken much

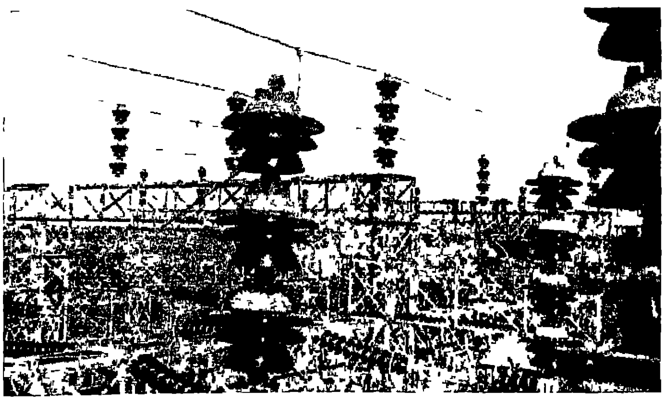


FIG 23 VICTORIA FALLS AND TRANSVAAL POWER CO WITBANK STATION BUSBARS

higher, and suspension insulators used The arrangement shown is, incidentally, rather easier to erect This detail picture also shows the manner in which tap connections were taken off from mid-span positions

METAL-CLAD EQUIPMENTS

In the foregoing no data has been given on metal-clad apparatus or equipments, since such gear is in a class by itself, involving its own special problems in design and meeting a definite group of operating requirements As is doubtless well understood, metal-clad switchgear is of purely British origin For many years operators

abroad steadily refused to "experiment" by using metal-clad gear, but since the war practically every country in the world has taken the step, and, once having done so, further installations have followed

As the name implies, all live metal is completely encased in metal Conductors are usually insulated with micanite, empire cloth, or micarta, and the space between such insulation and the outer, earthed casing, is filled with bitumen, oil, or a semi-fluid dielectric, so as to exclude air and moisture The insulation of conductors where they pass from section to section so far has fixed the upper limit for regular commercial products at about 35 kV. although special equipments for 66 kV have been built, and there are no technical, but only commercial, reasons why the same principle should not be applied up to any system voltage now in use

In Fig 24 is shown a cross-sectional view through a unit built by Metropolitan-Vickers Co , which may be considered as typical of the smaller and medium-sized outfits built by that firm for pressures up to 35 kV The duplicate sets of busbars, each set in its own metal casing, are located in the upper left-hand portion of the drawing The individual bars are each connected to a contact socket, which is at the back of a deeply recessed insulator, the outer surfaces of which are covered by an extension of the busbar casing Within the casing the busbars are insulated with a micafolium wrap, precisely like that used on generator stator bars, and the curved conductors with mica-silk tape, of such thickness as to provide in itself adequate insulation for the working voltage

In addition, the interior of the casing is filled solid with compound, leaving only a sufficient air space (in a pocket provided for the purpose) to allow for expansion due to temperature changes

Immediately beneath the busbar casings is one which houses the current transformers This also has a set of three contact sockets in recessed insulators, precisely as has each busbar unit At the lower end

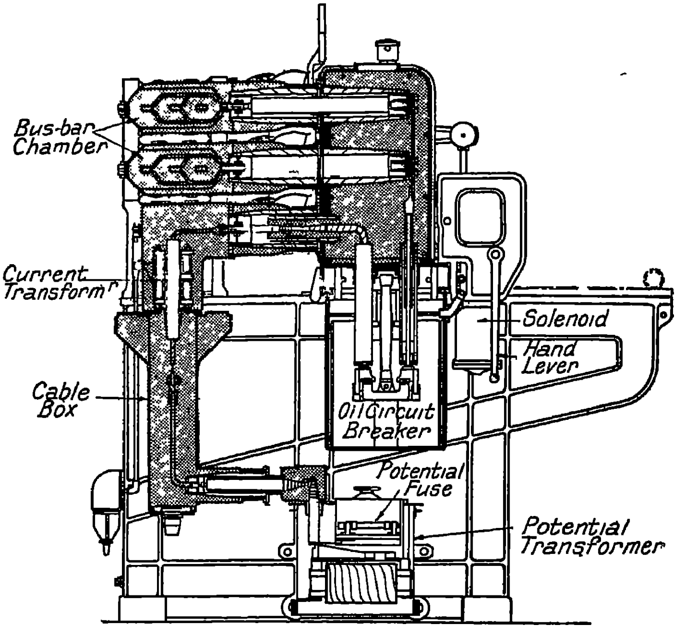


FIG 24 CROSS SECTION THROUGH METROPOLITAN VICKERS 35 KV METAL-CLAD EQUIPMENT

of the current transformer casing, there is bolted on the cable-end box. The conductors within the transformer casing are insulated in the same manner as are the busbars, and the casing itself filled with compound

The potential transformer, its primary fuses and protective resistances are all immersed in the same oil tank, this tank being mounted on wheels, and making

plug connection through recessed insulators in the cable box It is so arranged that the fuses can be lifted from outside the case, and until the potential transformer circuit has been broken in this way, the tank cannot be withdrawn from its contact sockets The object of this feature in design is to enable the fuses to be replaced, if necessary, without need for withdrawing the circuit breaker itself

The circuit breaker has plug contacts at the rear and is mounted upon wheels, which run on the upper surface of the side frames These permit the circuit breaker to be drawn forward so that the contact plugs are clear of the busbar and instrument transformer contact sockets In this position earthed metal covers fall over the openings to the fixed socket insulators so as to prevent risk of accident

The circuit breaker itself is of conventional design, and can be arranged for direct manual operation, operation from a distance through the usual system of levers and links, or by electrical means with a closing solenoid The plug and socket insulators for the higher voltages present a pretty problem in design, since if porcelain or other bulk insulation were used the irregular voltage gradient over adjacent surfaces would cause constant brush discharge, fatal in such a confined space Recourse is had to the condenser principle with the order of foil layers reversed in the socket insulator This ensures the same potential at all opposite points over the surfaces

Apparatus built by Messrs Reyrolle for roughly the same voltage and rupturing duty range also is built with the circuit breaker travelling along a horizontal track for isolation Certain minor differences in arrangement will be observed from Fig 25, the chief of which is the location of the potential transformer, which occupies the otherwise vacant space between the circuit-breaker tank and the current transformer

casing. The fuses are of a plugging pattern, withdrawing in a horizontal direction, and form the connecting link between the main conductors and the transformer.

The limiting commercial pressure for metal-clad gear —35 kV—is also about the limit of pressure for which potential transformers are a practical and economical proposition. Both makers employ series choke coils and current limiting resistances on their 35 kV units, to make quite certain that no trouble could arise from failure of a transformer winding.

In both the designs illustrated it will be seen that where duplicate busbars are used, the usual method of transfer from one busbar to the other consists in first opening the circuit breaker and then withdrawing it, so that the top set of plugs can be moved from the upper to the lower position or vice versa to enable them to make contact with the desired set of busbars. A simple interlocking device can be arranged to prevent the switch being pushed home unless all plugs are in one position or the other, i.e. to prevent making connection with, say, the main busbar on two phases and with the auxiliary busbar on the third phase.

At first glance this movable plug arrangement will strike an operator as very objectionable, although, in point of fact, in many plants it is not common for it to be necessary to transfer circuits on load from one busbar to the other. The duplicate busbar is most frequently used either for testing out a machine or cable after repair, for use during extensions, for periodical cleaning, or for use in the emergency or failure of the main busbar insulation. With metal-clad gear it may fairly be claimed that the last two functions are entirely unnecessary, while the first two only occur occasionally. In many cases, therefore, it is permissible to kill a circuit for the time necessary to change the

plug position, a matter of from five to twelve minutes, according to the size of the gear

It has to be recognized that all systems are not so happily situated, and that for them rapid transfer is essential Metropolitan-Vickers Co incorporate an oil-immersed selector switch in equipments to be used in such circumstances, the arrangements being shown in Figs 26 and 27 When the selector switch blade is narrow, as shown in Fig 26, interlocks compel the opening of the associated circuit breaker, when transfer can be effected rapidly, without having need to parallel the two sets of busbars If even momentary interruption of supply is impossible, the broad selector blade in Fig 27 is used, and it is necessary also to have a busbar coupling switch on the equipment The bars are paralleled through the coupling switch, and an interlock thereon then releases a removable handwheel which alone can be employed to move the selector blades In the course of transfer the broad blade is never out of contact with one or other set of busbars, so that supply is not interfered with Only when the selector has reached the end of its travel up or down can the handwheel be taken away, and until it is replaced on the busbar coupler the latter cannot be reopened Mistake-proof operation is thus ensured

A little consideration will show that with metal-clad gear of the horizontal draw-out pattern, busbar coupling switches can be arranged in the same mounting centres as the regular circuit breakers, the plugs corresponding to the two sets of busbars being connected direct to the two sides of the circuit breaker, the lower casing containing cable box, instrument transformers and the associated sockets being unnecessary and omitted

Similarly with busbar section switches No lower casings are needed at this point, so that the busbar

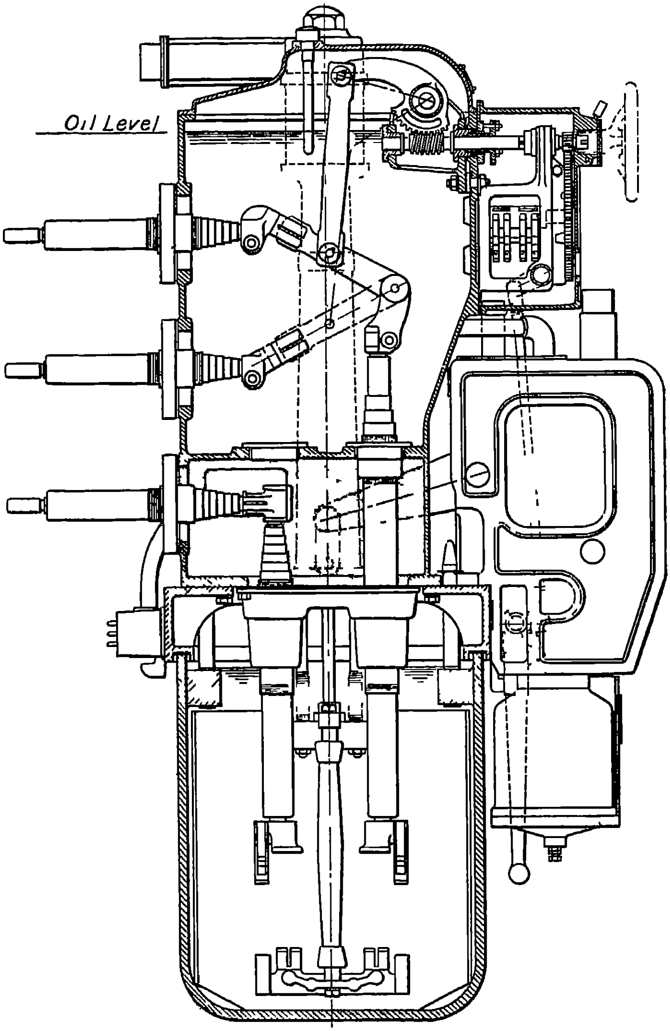


FIG 26 OIL-IMMERSED BUSBAR SELECTOR SWITCH INVOLVING INTERRUPTION OF SUPPLY

casing with its sockets from one side of the equipment can be deflected down into this space, or carried above the usual location for the upper set of bars, the section oil switch back plugs being placed to correspond

Metal-clad equipment built by Messrs Ferguson Pailin incorporates a circuit breaker which is moved

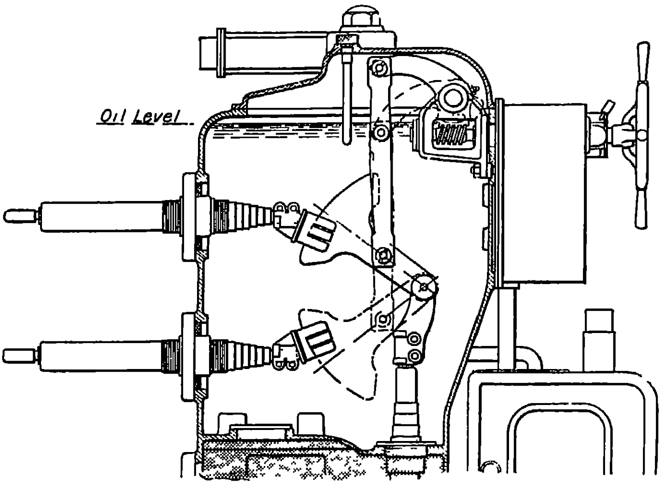


FIG 27 OIL-IMMERSED BUSBAR SELECTOR SWITCH FOR USE IN CONJUNCTION WITH BUSBAR COUPLING SWITCH

vertically downwards when isolating it from the busbars, the scheme being apparent from Fig 28, which shows a medium capacity circuit breaker with a single set of busbars At times this design may be found to take up less floor space than is needed with horizontal isolated gear The advantage is not so great or so certain as appears at a glance, since the location of the cable box makes necessary greater space behind

The actual length of enclosed conductors is reduced, as is the number of insulators, and if such items can

be regarded as potential sources of weakness, vertical isolated apparatus is so much the better

When two sets of busbars are necessary, a twin

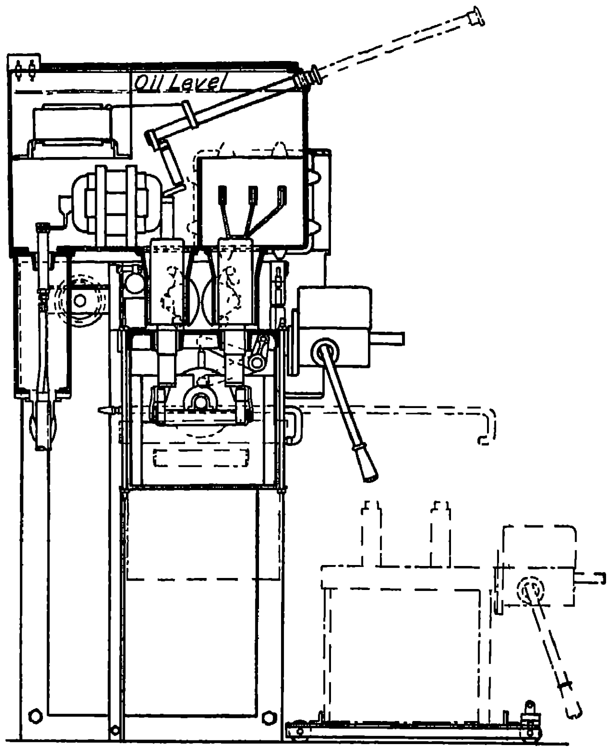


FIG 28 CROSS SECTION THROUGH FERGUSON PAILIN SINGLE BUS, OIL-FILLED METAL-CLAD GEAR

circuit breaker is used, i e a single top casting and tank containing two distinct circuit breaker movements, one associated with each set of busbars Fig 29 shows a sectional view of such an outfit, embodying

a breaker of large capacity The design makes possible transfer from one set of busbars to the other without interrupting supply, and without employing any special bus coupling switch, since closure of both breakers in any one tank necessarily parallels the two busbar systems The process of transfer is quicker than with any of the other devices available

The mechanical features of this line of apparatus have been worked out very neatly The circuit breakers incorporate the makers' patented low-energy trip gear, the burden of which is only 1 5 VA, about one-twentieth of the figure for the conventional trip devices used elsewhere Interlocking is arranged on the complete basis now a standard feature of all metal-clad designs, the vertical movement lending itself to quite simple ways of accomplishment A winch is built into all units, to effect isolation, lower the tank when isolated, or lower the complete breaker, at will This winch is hand operated on the small sizes and motor operated on bigger units

Messrs Ferguson Pailin have used both bitumastic compound and also transformer oil as a filler in equipments of the types illustrated The oil filler is easier to handle if the job must be done on site, but the necessary oil-tight joints between casings are a distinct problem On the whole, it is generally deemed better to use nothing more fluid than a material of a thick syrupy consistency at ordinary room temperatures, and then only if it may be necessary to remove it at intervals, as when changing current transformers

In all makes of metal-clad equipment the casings are filled with dielectric as far as ever possible in the factory Where conductors pass out of a casing, the opening is made compound tight by a thick plate of micarta Before filling, the casings are heated and the contents dried out, so that there is no risk of trapping

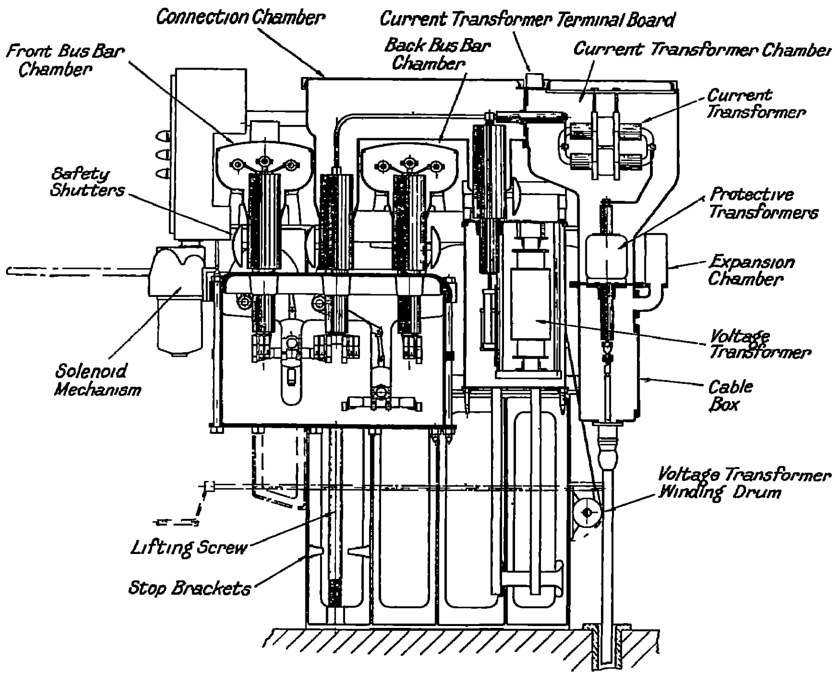


FIG 29 FERGUSON PAILIN METAL-CLAD SWITCHGEAR WITH DUPLICATE BUSBARS AND SELECTOR CIRCUIT BREAKERS

either air or moisture The joints in the casing are felt or rope packed, and also sealed with Keen's cement, so that there is no possible chance of compound leaking under any conditions which may arise in service

The compound used for filling varies according to the voltage on which the apparatus is used Although the very hard compounds usually have the highest dielectric strength, they are also more liable to fine cracks if not cooled very slowly The desirable mechanical characteristic is flexibility or toughness rather than hardness It is usual to specify when purchasing this material that a slab of given thickness shall withstand a stated hammer blow without fracture The pouring temperature is commonly between 250° F. to 280° F

The range of operating temperature which is at all likely to be experienced in practice may be set at from freezing point to about 120° F Over such a range the classes of compound used would increase in volume about 2½ per cent It is well known that all compounds "flow" even at temperatures far below their melting point, so that it is only necessary to provide in each casing sufficient air space in a top pocket out of the way of conductors, to prevent any stresses in the casing metal due to expansion of compound

Those portions which cannot be filled in the factory, e g the short lengths coupling busbar sections and the cable end box, are so designed as to have large filling openings readily accessible Experience has proved that the users themselves can readily complete erection without any risk of trouble subsequently occurring

The use of conductors buried in compound introduces unusual features, but these are not so serious as they appear to be at first sight The fact that the conductors are at very close centres naturally means that under short-circuit conditions the mutual repulsion between

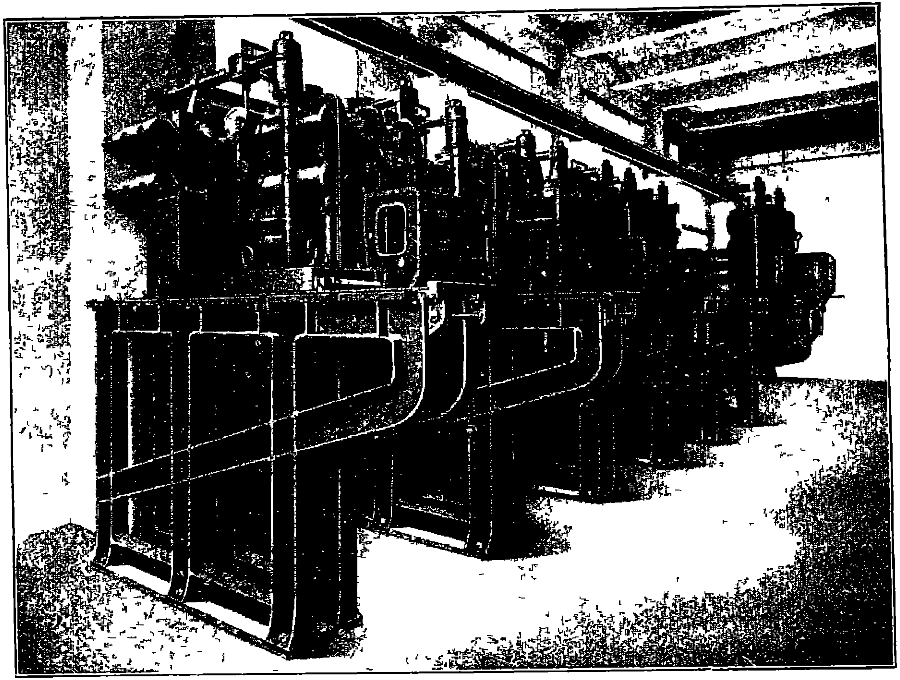


Fig 30 Metropolitan-Vickers Metal clad Board on the 33 kV System of the County of London Electric Supply Co, Ltd

them reaches a very high value, but the presence of the compound acts as a shock absorber, and, in point of fact, it has been found impossible to burst a compound-filled busbar unit or move the conductors, even when subjecting it to the highest current values which could possibly be experienced in practice

The second point which is liable to cause apprehension is that of heating, since there is no chance of using air as a cooling medium between individual conductors Here, again, research has shown that the casings as a whole have very high thermal capacity, and the big area on the outside of the casing does good service in radiating heat generated In practice, equipments which are designed to comply with the British Engineering Standards maximum temperature rise of 30° C above surrounding air are worked on a current density ranging from 1000 amp per sq in with a normal current of 1000 amp down to 350 amp per sq in with a normal current of 3000 amp The corresponding figures for open busbars would be approximately 1150 amp per sq in and 850 amp per sq in The difference is, therefore, much less than would be expected

A very good idea of the general layout which can be obtained with metal-clad gear is given by Fig 30 As no live conductors are exposed, and there is absolutely no possibility of gaining access to them, special guards or screens are unnecessary The only device in the room not supplied by the makers is a light, hand-operated overhead crane Even this is not essential, as the regular tank lifter and carriage would be adequate for transport service The circuits are spaced on 6 ft 3 in centres, which is rather less than half the space needed for an open-type circuit breaker The complete height is about the same as that of an ordinary circuit breaker by itself, and the space needed front

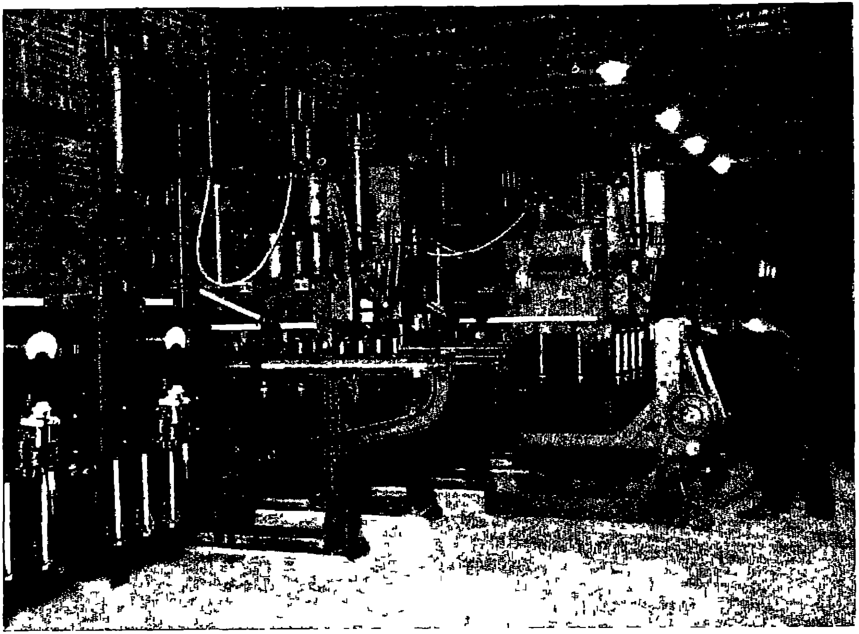


FIG 31 B T-H 33 kV METAL-CLAD SWITCHBOARD

to back is only about 50 per cent greater than would be necessary for an open cubicle

The British Thomson-Houston Co also build metal-clad gear of the horizontal draw-out type, the general construction of which may be gathered from Figs 31 and 32 The arrangement differs from those so far studied in that the cable sections are located above those containing the busbars This brings both current and potential transformers to the upper part of the structure A round casing will be noted behind the potential transformer at the upper left-hand corner of Fig 31 This contains the oil-immersed fuses, which, with their plug connectors, are arranged in the form of an inverted " U," and may be removed while the circuit is alive by means of a pulley block carried on the run-way slung under the ceiling

In Fig 33 is shown a board composed of units such as are indicated in detail by Fig 29 The general disposition of parts will be apparent by a comparison of these two On the outside of the right-hand frame will be noted the driving chain from motor to lifting-screw, and, immediately beneath, the cam lever which sets the limit of travel for isolation, tank removal, or complete circuit-breaker removal The small ironclad air break switch on the front face of each right-hand frame controls the motor With the circuit breaker plugged into contact with the busbars, this cannot be closed unless both elements of the breaker itself are open

It is fair to generalize by saying that on a 33 kV system a metal-clad equipment will never require more than 25 per cent of the building necessary for an open, indoor arrangement, and will generally be even more compact For this reason metal-clad gear is frequently the cheapest job when completed

All makers have found it necessary to adopt new

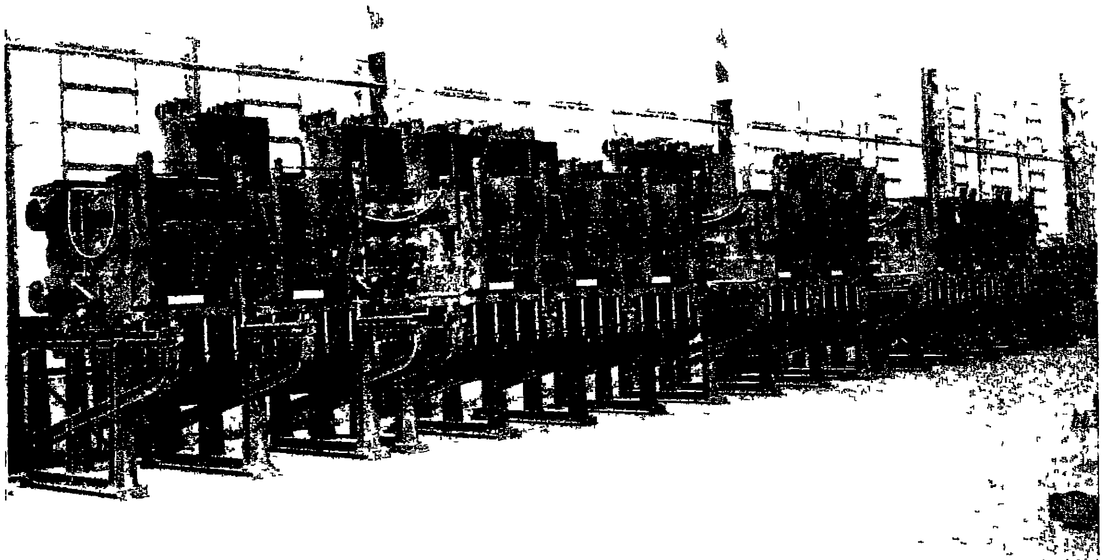


FIG 32 B T -H 22 kV METAL CLAD SWITCHGEAR

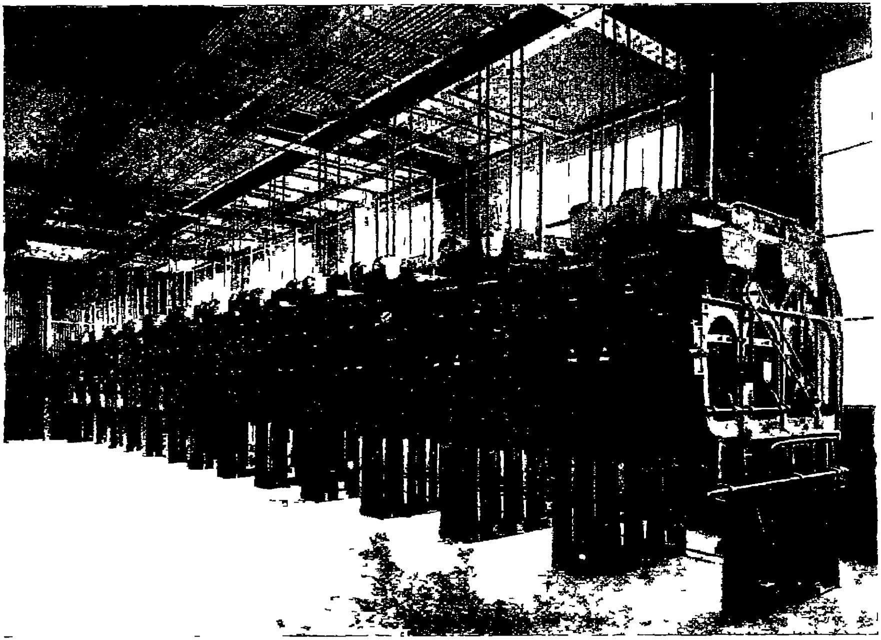


FIG 33 FERGUSON PAILIN THIRTEEN PANEL METAL-CLAD BOARD

lines of design when producing apparatus for use in the modern super-generating station, because of the great weights and bulk involved The broad idea in Messrs Reyrolle's design, known as the Type "M," will be clear from Fig 34, taken from the paper read before the Institute of Electrical Engineers in 1925 by Mr H W Clothier, the managing director of that firm

The circuit breaker occupies the central row of tanks, and embodies a novel combination of conventional double break main contacts with a single break arcing element The arc takes place between two arms, which spring away from each other, and which are located above the main contacts Oil-immersed isolating and selector switches are provided for normal operating purposes

When it is necessary to inspect or work on the interior of the circuit breaker, the top plate carrying the contacts, mechanism, and solenoids for the circuit breaker, together with those isolator contact studs which are connected direct to the circuit breaker, is lifted as a unit, as indicated in dotted lines, Fig 34 Electrical interlocks ensure that removal of these parts cannot take place unless the isolator and selector switches are all open

The isolators and selectors are operated by levers located on the switch structure, and on the feeder side provision is made so that cables may be earthed if desired after isolation Ring-type current transformers are used, these being located in the isolating switch tank together with the potential transformers, and the fuses for the latter It would seem better to place these fuses where they would be accessible without having to open the associated main circuit breaker and its isolators

In their metal-clad designs for maximum breaking capacities, Messrs Ferguson Pailin still adhere to the

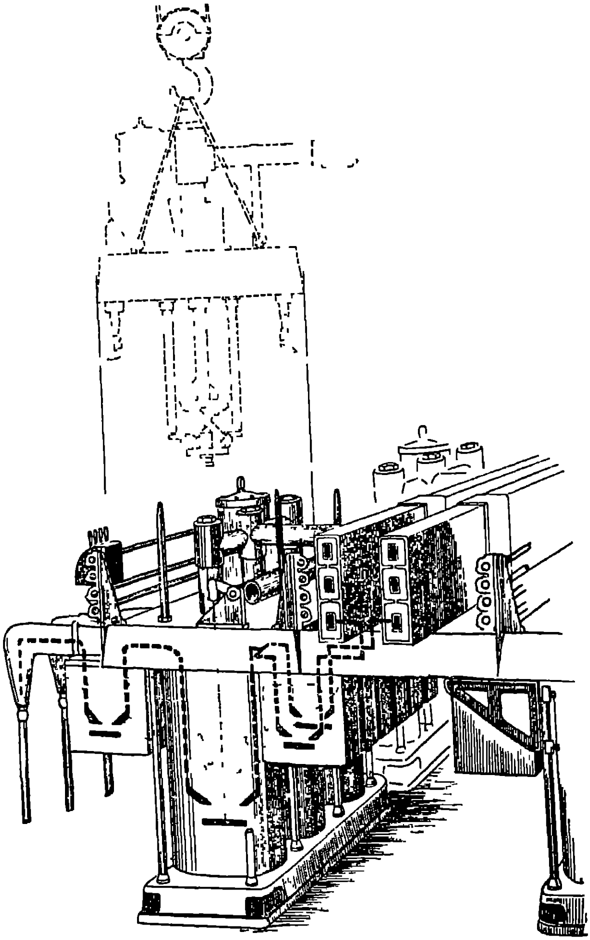


FIG 34 METAL-CLAD UNIT FOR SUPER GENERATING STATION WORK

principle of vertical isolation, as will be seen from Figs 35 and 36, but the duplicate circuit breakers are kept entirely separate This is a distinct improvement

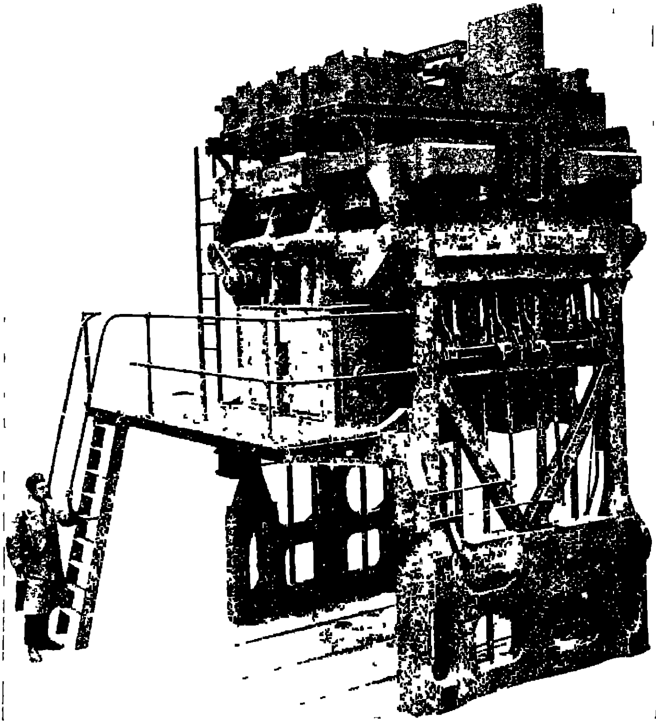


FIG 35 GENERAL VIEW OF FERGUSON PAILIN SUPER GENERATING STATION METAL CLAD UNIT

on the smaller duplicate bus designs Each phase is in its own circular cast-steel tank, three being bolted together so that they may be handled as a unit Independent motor manipulating gear is provided for

each circuit breaker, the one device being arranged so as to be used at will for dropping the circuit breaker to the isolated position, lowering the tank of an isolated breaker for contact inspection, or for lowering the whole breaker on to the floor Wheels permanently carried on the tank bottom facilitate removal when lowered right down to the floor

The circuit breaker itself is of the conventional two-break design, using controller fingers for main and arcing contacts Micarta insulation is employed throughout A header pipe is built into the structure above the centre of each line of tanks and, when the circuit breaker is in the raised position, a vent pipe in the top fits into an opening in the header A flap-valve closes this opening when the breaker is down As in other Ferguson Pailin circuit breakers, pebbles are placed in the header to prevent ejection of oil

Single-phase potential transformers are used, connected phase-neutral This enables phases to be separated completely throughout the equipment These transformers are carried on runways at the top of the structure and are connected in circuit through plugging contacts

With the obvious exceptions of the circuit breaker and those for instrument transformers, all casings are filled with bitumastic compound, the covers of the casings being domed to allow for expansion

The safety devices and sequence controls are all attained by mechanical interlocks, and mechanically-operated signals show the position of all parts Coloured light signals are used in addition, being intended primarily for purpose of remote position indication

The largest metal-clad equipment built by Metropolitan-Vickers Co is illustrated in Figs 37 and 38 The circuit-breaker capacity in this and the two preceding designs is of the same order In the equipment

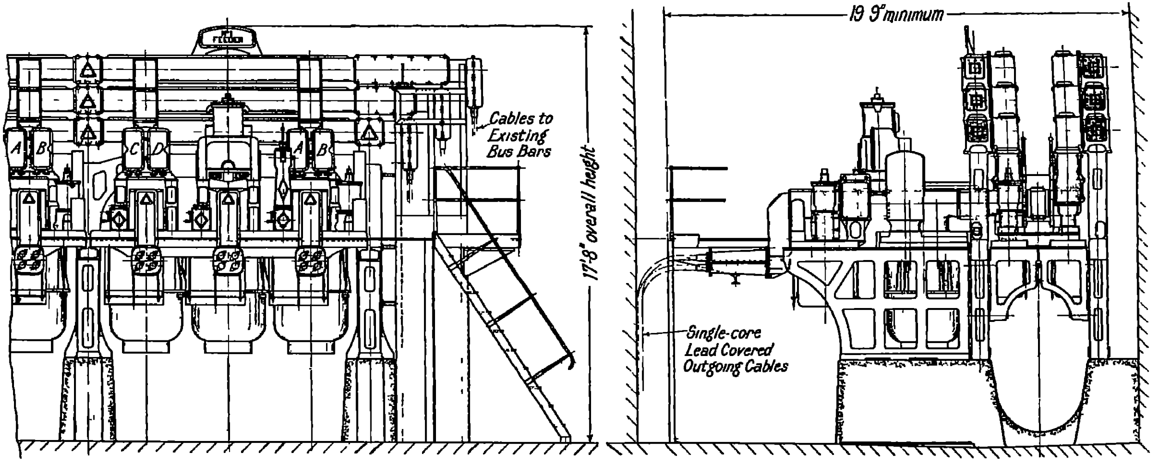


FIG 38 SECTION THROUGH METROPOLITAN-VICKERS METAL-CLAD GEAR

A—Isolating switch contactor
B—No 2 selector switch contactor
C—No 1 " " "
D—Oil circuit-breaker contactor

shown, not only the circuit breaker, but also the selector and isolating switches, are solenoid-operated from the control room, so that all normal operations, including transfer from bus to bus, can be carried out from a distance Additional means for direct hand operation are provided on the gear itself, these being meant primarily for maintenance purposes, although they could be used in the emergency of direct current supply failing When using the remote control devices, electrical interlocks ensure proper sequence of operation, but the mechanical locks on the apparatus itself, furnished for use when working by hand, function also as back-up interlocks should anything go wrong with the electrical gear

The contacts on circuit breaker, selectors, and isolators, are all interchangeable, and embody the continuous leaf " Y " main brush, with heavy controller finger arc contacts The circuit-breaker contact studs are braced against repulsive forces due to short-circuit.

Each phase is accommodated in a separate welded steel tank, which finishes at the top with a broad machined flange This flange covers the edges of a series of concentric grooves machined in the top casting Small openings, irregularly spaced, connect the grooves, so that the whole forms a labyrinth outlet passage for gas, which effectually traps oil and permits it to return to the tank when the pressure has died down

A motor-operated transfer truck serves the circuit breaker, interlocks cutting off supply to the motor until the circuit is properly dead and isolated The selector and isolator tanks are raised and lowered by winch gear built into the structure, but separate hanger bolts are used to relieve the wire ropes of strain when the tanks are in place.

The potential transformers are located one phase in each isolating switch tank The protective resistances

and fuses are normally immersed alongside, but are carried on an insulating plate which can be withdrawn upwards, without breaking the main circuit In this position the potential transformer is disconnected and the fuses dead and thus safe to renew

When the main circuit breaker is opened and isolated, a further movement of the fuse base makes room for the introduction of a terminal, specially shaped to make contact with that isolator contact which is connected to the cable This terminal is connected to the station test transformer It is thus possible to put an over-potential test on the cables without subjecting the circuit breaker insulation to unnecessary electrical stresses

. . .

The early designs of metal-clad gear were often criticized, with some justice, for a lack of flexibility in operation Enough has been written above to show that this accusation no longer holds good Experience has demonstrated insulation troubles to be almost unknown, largely due to the complete exclusion of moisture, dirt, and vermin Similarly, it has come to be an accepted fact that metal-clad gear, erected and at work, involves a smaller capital outlay than practically any other construction which could be used on super-generating voltages There is not the slightest doubt that the use of this class of switchgear on pressures up to 35 kV will ultimately become the standard practice, unless, indeed, some entirely novel means of current control be discovered meantime

SECTION X

SUPER-GENERATING VOLTAGE SWITCHGEAR (APPARATUS)

BY

W ANSELM COATES, M I E.E,
FEL A I E E.

SECTION X

SUPER-GENERATING VOLTAGE SWITCHGEAR

(APPARATUS)

INSULATING MATERIALS

Broadly speaking, the design of apparatus for super-generating voltages boils down to a series of problems in insulation application The currents involved are usually of such small magnitude that no difficulties arise due to heating or electro-magnetic effects It is well, therefore, to begin this section by reviewing some of the characteristics and properties of the available materials

Value of Thickness. All insulating materials have in common a characteristic decrease in unit dielectric strength with increasing thickness Curves relating to particular dielectrics will be found under the appropriate heads hereafter If means can be found to use several thin pieces of insulation in series and to control the voltage subtended across each, the materials will be employed more advantageously than if an attempt be made to harness the full pressure with one single lump of insulation material

The desirability of the course indicated is often emphasized because of the manufacturing difficulties attendant upon producing great thicknesses of many classes of insulation In fact, it is impossible to produce some materials in the thicknesses which would be necessary in a single piece to withstand the working pressures in use to-day

When two or more condensers are connected in series across a given voltage, the potential difference over each is in inverse ratio to their several capacities Herein lies the method of voltage control, the need for which has just been indicated

The best known, and most obvious, case of the application of this method is the condenser bushing, to which some detailed attention will be devoted later In this, metal layers are used to subdivide the insulating material, the metal forming the condenser plates The same effect of controlled voltage distribution is observed whenever insulating materials of different specific inductive capacities are brought together Hence, the design of compound insulating bushings, strings of suspension insulators, and, indeed, that of most multi-shed pin insulators, involves the consideration of the voltage gradient which will exist through each element Lack of appreciation of this fact was probably at the back of more cases of insulation failure in early apparatus than was any other one cause

Effect of Temperature. The dielectric strength of all materials is affected by temperature in some measure Fibrous materials are markedly affected and in the following section curves are given showing the order of depreciation in dielectric strength with rising temperatures It must be noted, however, that all characteristic data given should be used with reserve, and the maker's figures obtained for the material it is intended to use in actual design work

Porcelain.

Ultimate strength, compression	15,000 lb per sq in
,, ,, tension	1,800 ,,
Specific gravity	2 43
Specific inductive capacity	3 4–4 4

In switchgear manufacture, porcelain is by far the most widely used insulating medium, this pride of place

being due to high dielectric value, to the fact that it is virtually non-hygroscopic, to the ease with which it can be made to shape, and to its relatively low cost

There are many processes of manufacture, and almost every maker has his own ideas about constituent materials, which, although kept secret, do not, as a rule, appear to have much bearing upon the finished insulator Hopes are entertained in certain quarters

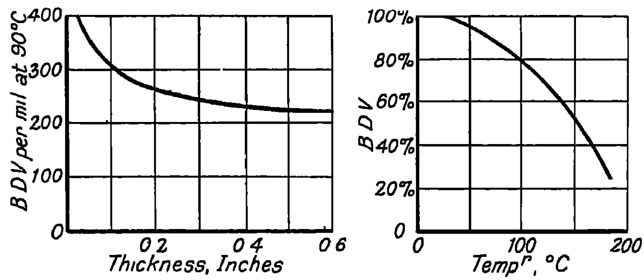


FIG 1 CHARACTERISTIC CURVES FOR WET PROCESS PORCELAIN

of producing an electrical porcelain of improved mechanical properties, by modifying the raw materials, but so far success in this direction has been confined to very small pieces

Porcelain, shaped by forcing under pressure into a steel mould the constituent materials when only slightly damp, is termed "dry pressed," and being mechanically inferior and also slightly porous, should never be employed for any but low-voltage work

Superior physical properties, with a much closer knit body, are obtained by one or other of the "wet" processes, which may involve turning an extruded piece of clay on a lathe, throwing and turning on a potter's wheel, pressing and turning in a jigger or casting in a plaster mould The choice of these is a matter for the maker, since the finished article can be of the same

quality if made by any of them In general, the first is used for pieces of rather small diameter required in small quantities, the potter's wheel is adopted for larger pieces in limited quantity, the jigger for small and medium repetition work, and the casting method for big repetition work Cast porcelain is more usual in America than here

During the firing process the shaped clay shrinks considerably and becomes soft, so that supports may be necessary to prevent deformation The amount of shrinkage depends on the temperature of firing and on the initial water content At the best the dimensions of the finished part must be regarded as subject to variations greater than would be tolerated with practically any other material, however made Undoubtedly, the best way of designing porcelain insulators is for the electrical engineer to rough out his ideas and then consult with the ceramic expert in regard to manufacturing possibilities

It is a temptation to conclude this section by stating that porcelain should not be used in tension, because designers so frequently abuse it when so employed As will be noted from the table of physical constants above, the ultimate tensile strength is low and, in many instances, only a little consideration is needed so to modify the design as to change most of the stressing from tension to compression Many forms of apparatus exist in which porcelain in tension has been applied intelligently and with entirely satisfactory results

Micarta.

Ultimate strength (tubes)	
Compression	10,000/12,000 lb per sq in
Tension	8,500 ,, ,,
Specific gravity	1 3–1 4
Specific inductive capacity	
Shellac, 25° C–100° C	4 3–7 3
Bakelite, ,, ,,	5 9–14 7

Micarta is a generic name given to all those materials composed of paper bonded with a natural or synthetic varnish under pressure There is no mica in these materials, the name presumably having been given by a rather optimistic inventor who thought he had a material comparable with mica Micartas are on the market under a variety of trade names, such as " Bakelite Dilecto," " Paxolin," " Pertinax," etc

Attention is drawn to the curves in Fig 2, which

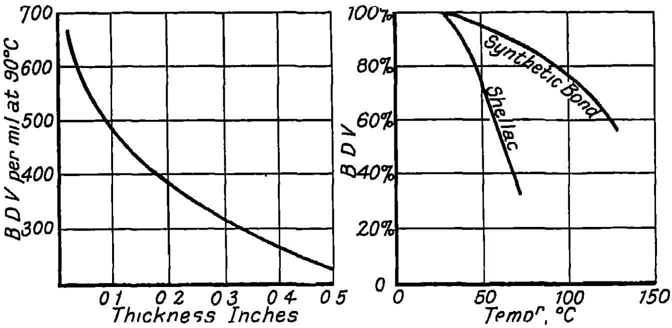


FIG 2 CHARACTERISTIC CURVES FOR MICARTAS

show the effect of increasing working temperature, since it is more marked in this than in any other material commonly used by switchgear makers It will be noted that shellac-bonded micarta suffers most in this respect, due to the shellac itself softening The specific inductive capacity also is affected by temperature to a much greater extent than with porcelain and other non-fibrous dielectrics

In the form of flat plates or sheets micarta has a limited field of application, chiefly because it is so difficult when cutting them, to avoid slightly separating the striations at the edges Such separations form fine

capillary cracks and involve a risk of flash-over between electrodes mounted near the edges, unless very long creepage surfaces can be allowed For tank linings and the like, this difficulty does not occur

Stout-walled tubes of micarta are frequently used as tension insulators, both in air and in oil It is also largely employed by wrapping the material directly on to the conductor it is desired to insulate, and completing the manufacturing process in place Used in these manners the mechanical properties of micarta are the great attraction, since it is tough and strong, while having a certain amount of flexibility Moreover, it can be made true to dimension, can be cut and drilled, and the best grades will even take a screw thread

Care is necessary in shaping the metal fittings, especially with micartas which have synthetic bonds, because of the risk of starting, from points of concentrated electrostatic stress, the carbonized, tree-like markings termed "tracking," which ultimately cause the insulator to flash-over

In making micarta, as indeed with all wrapped insulating materials, the great secret is to exclude all air from between layers of paper In fact, with given paper and bond, specific gravity and breakdown voltage increase together in this material Visual inspection will not reveal the presence of air pockets which, though small, may be harmful in time Measurement of the dielectric watt loss under full working potential is about the only really satisfactory test which can be applied, this method having the added advantage of revealing also "green" material, i e that from which all the varnish solvent has not been driven off during manufacture

In general it may be said that micarta is a material for experts, both in manufacture and in application,

but that in the right hands it is one of the most valuable insulating agents yet available

Micanite. This is the material made with mica flakes affixed to a carrier of sheet silk or paper by means of a binding varnish such as shellac, which is sometimes confused with micarta It has excellent insulating properties, but practically no mechanical qualities, except in compression, and is, moreover, affected by the presence of oil For these reasons, there are very few possible points of application in high-voltage switching apparatus for micanite, its great field of use being in rotating machinery, where mechanical support can be afforded over the major part of the insulation surface.

Timber.

	Hickory	Maple
Ultimate strength		
Compression	9,500	6,000 lb per sq in
Tension	11,000	10,600 ,, ,,
Specific gravity		67 to 75
B D V per inch length along grain of impregnated material	5000–8000 volts	

In places where insulators of great mechanical strength are necessary, treated hickory, maple, and other hard woods are frequently used As a rule, the treatment consists of vacuum impregnation with paraffin wax, after the shaped timber has been thoroughly kiln seasoned and dried out in a vacuum oven Some makers prefer to substitute linseed oil for the wax, the timber being baked after impregnation to oxidize the surface oil and thus seal the pores

By these methods, the whole body of timber is not

impregnated, rather is an impervious casing formed, so that it is necessary for all cutting work to be finished before treatment The life and toughness of the material is not affected by these processes Provided, therefore, that good straight-grained timber is selected in the first place, this material is extremely useful, especially to those manufacturers who do not have facilities for supervising the production of their own micartas

Fullerboard and Elephantide.

Ultimate strength—tension	5000/6500 lb per sq in
Specific gravity	1 0/1 3
Specific inductive capacity (in oil)	5 10–5 37

Fullerboards are employed in places where electrical, rather than mechanical, properties are necessary, as, for example in oil-filled bushings, as tank linings, and for terminal boards, spacers, etc Being of a fibrous nature, they should not be used exposed to the air, but must be under oil or buried in compound

Fullerboard (or, more properly, pressboard) is made in a variety of densities, suited to particular applications and to the degree of mechanical support which can be afforded it in use In switchgear work, the dark material, often called elephantide, is chiefly used for tank linings and the soft absorbent varieties as the inner tubes of bushings and protective separators in oil-immersed apparatus As will be seen from curves shown in Fig 4 when compared with Fig 3, these materials have very high electric strength when soaked in switch oil

Paraffin Wax.

Specific gravity	0 85/0 92
Specific inductive capacity	1 8/2 0
Coefficient of expansion, per ° C at 0–38 ° C	0 000107– 00013%

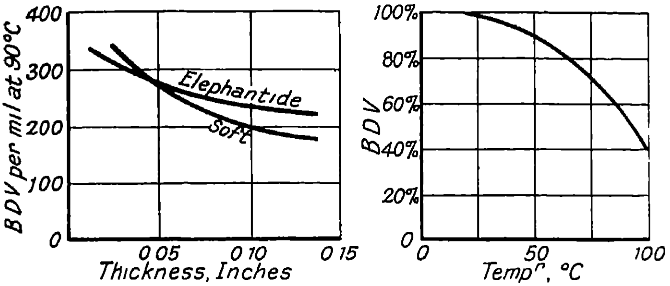


FIG 3 CHARACTERISTIC CURVES FOR FULLERBOARDS IN AIR

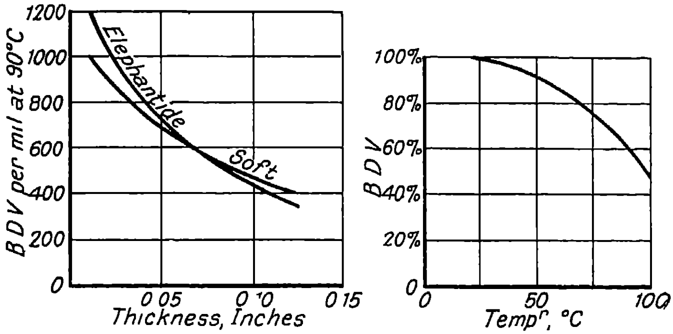


FIG 4 CHARACTERISTIC CURVES FOR FULLERBOARDS IN OIL

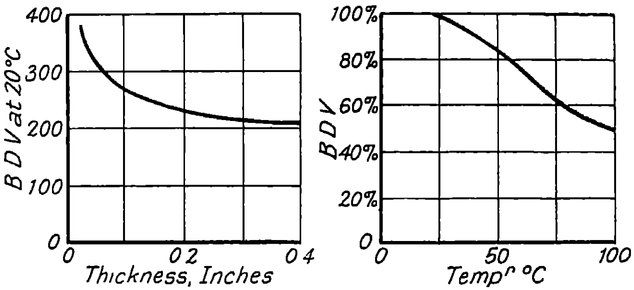


FIG 5 CHARACTERISTIC CURVES FOR PARAFFIN WAX

Paraffin wax is principally employed as a filler a useful dielectric which when melted can be poured into the spaces between solid insulating materials, thus excluding all air and moisture In this manner Continental designers are very fond of using it inside compound bushing insulators

Bitumen.

Specific gravity	1 07–0 999
Specific inductive capacity	3 76
Coefficient of expansion, per ° C while solid	0 03%

Bitumen is the filling material most favoured by British engineers, immense quantities sold under a

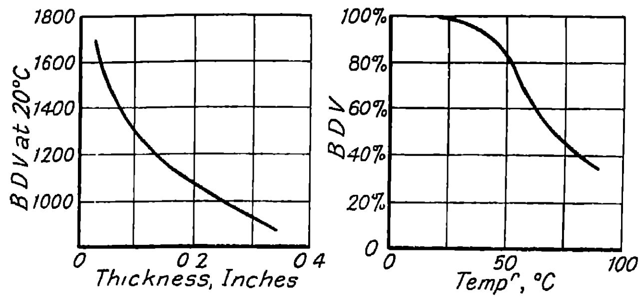


FIG 6 CHARACTERISTIC CURVES FOR BITUMEN

variety of trade names being used annually for filling joint boxes, casings of metal-clad switchgear and so forth In high-voltage apparatus the chief application is for filling the space between condenser bushings and their surrounding porcelain weather-casings

When pouring either bitumen or paraffin wax it is essential that the object into which it is poured be heated, especially if there are any narrow passages, otherwise the filler may solidify prematurely and trap

air inside Such trapped air may become ionized and later cause internal flash-over

On the other hand, if the filler be poured at too high a temperature, gas bubbles will be formed which may not be able to rise to the surface and escape, thus again leaving voids in the mass of the filler

It will be realized that the results of an internal flash-over may be quite serious, as it is possible for the ensuing explosion to be extremely violent

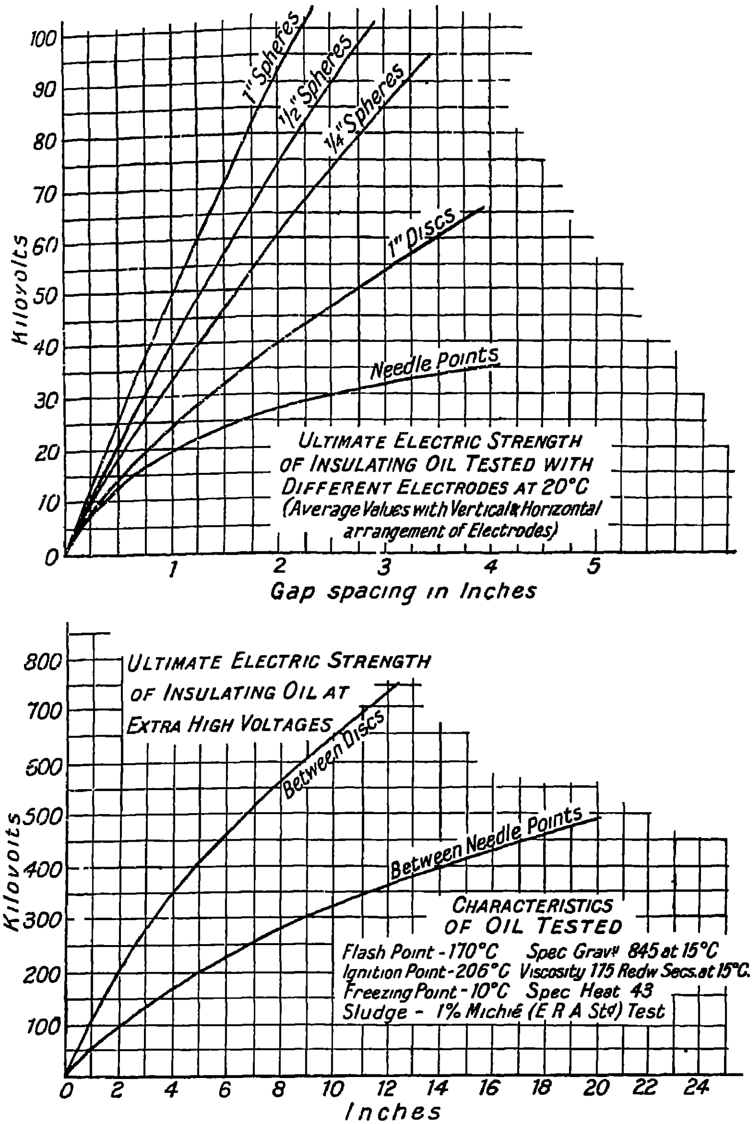
It is obvious that in pouring the filler it is necessary to keep between the two temperature limits

Oil. (Class "B," B S S 148/1927)

Specific gravity	0 84/0 88
Specific inductive capacity	2 27–2·14
Coefficient of expansion, per ° C at 0–100 ° C	0 075–0 079%

Oil is not only used almost universally as the medium in which current is actually interrupted, but is also used to some extent as a filler, in bushings, instrument transformers, and so forth The desirable characteristics of switch oils are fully dealt with in B S S. 148, 1927, and, indeed, it may be felt that the subject of switch and transformer oils has been dealt with in the Press *ad nauseam* One aspect, however, does not yet appear to have had due stress laid upon it—the question of purity

Oil which meets the breakdown voltage test specified in B S S 148 (30 kV across the standard 4 0 mm gap) can at best only be regarded as commercially dry The same oil if absolutely free of all moisture would show a test figure of 60/80 kV across the standard gap The addition of water lowers the electric strength very rapidly at first, but the curve quickly becomes asymptotic Beyond this point water added to otherwise clean oil does not affect the B D V unless the two are



FIGS 7 AND 7A ELECTRIC STRENGTH OF INSULATING OILS

("*Electrical Insulating Materials*" A Monkhouse)

emulsified A short time suffices for the emulsion to settle out, after which the oil reverts to the saturated figure Even the addition of colloidal carbon and cotton fibres (the two most likely impurities to become present in practice) affect very little the electric strength of oil otherwise pure, i e perfectly dry

Switch oil is very hygroscopic, so much so that a sample exposed to the air will vary in electric strength with changes in the atmospheric humidity In consequence, it is quite impossible in practice to keep oil chemically dry The B S S test figure of 30 kV is, in fact, a practical compromise which recognizes the presence of a certain unavoidable degree of moisture

If carbon or fibrous material is present in such commercially dry oil, the breakdown voltage decreases to a much lower figure than when only one impurity was present, and it continues to fall The explanation is that the particles of carbon or fibrous matter act as carriers for the water, forming up along the potential stress lines Their presence also permits much more water to be held in suspension

Herein lies the real reason why great care should be given to maintain switch oil in good condition It is not practically possible to design apparatus so that it will work satisfactorily no matter how badly the oil has deteriorated, and the British Standard test figure is the compromise agreed upon as reasonable by operating and designing authorities

The practical impossibility of keeping oil really dry in service results in the apparent anomaly of improved unit B D V with increase in temperature, the fact being that heating actually drives off some water

The foregoing does not pretend to do more than introduce to the reader the broad idea Those who wish to study more deeply the subject of insulation *per se*, are referred to *Electrical Insulating Materials* by

Allan Monkhouse (Pitman), from which work certain data herein have been extracted

INSULATORS

In the previous pages have been reviewed the principal materials employed in the manufacture of

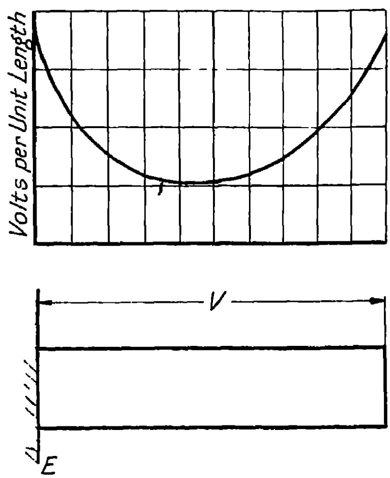


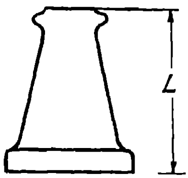
FIG 8 POTENTIAL GRADIENT OVER CYLINDRICAL INSULATOR

insulators for high-voltage apparatus The completed article will now be considered.

Porcelain Post Insulators (Indoor). If voltage be impressed across a simple cylinder of insulation, one end of which rests on an earthed plate, the potential gradient from end to end over the surface will not be uniform, but will vary somewhat as indicated in Fig 8 The uneven gradient results because from every point on the surface there are really two parallel dielectric paths—that through the dielectric itself and that through the surrounding air If, for any reason, the

potential difference across any part of the surface is greater than that necessary to break down the air path, a local brush discharge will start The effect of this is to short-circuit a section of the dielectric, causing a redistribution of the potential gradient, in which all other portions of the dielectric will be stressed higher than before Brush discharge will then start from a new point, and the process develop progressively until the cylinder flashes over

To use the dielectric to best advantage, it is necessary to shape the material and more especially the metal fittings, so as to effect a balance between the capacity paths, and thus stress all parts of the surface uniformly



Rated kV	Axial Length Inches
33	13
44	16
55	19½
66	23
88	29
110	36

FIG 9 DESIRABLE AXIAL LENGTH OF INDOOR POST INSULATORS

The profile of modern post insulators for indoor use is practically smooth, any irregularities introduced being rather by way of ornament than of real value The practice is to regard the axial length (L in Fig 9) as the important dimension The slightly conical shape is dictated purely by reason of the mechanical loading expected, and is characteristic of all modern designs of post insulators Since single-piece porcelain post insulators are now used but rarely over 60 kV, the question of voltage gradient ceases to be a very prominent one In dusty situations corrugations may be introduced to increase the leakage path without making the axial length unduly great A few manufacturers still use one-piece porcelain posts for outdoor work, and in this case, the corrugations are replaced by rain sheds similar to those used on bushing casings

The loads which have to be supported usually make necessary a considerable cross section of porcelain at the base, and, since it is not practicable to vitrify uniformly very thick pieces, posts for higher voltages are always made hollow Care must be taken in mounting such porcelains not to trap air in the interior space

Outdoor Post Insulators, up to 60 kV. For outdoor work up to about 60 kV, supporting insulators are usually of the same general design as pin-type line insulators In fact, the latter are commonly employed, where the mechanical loading permits All such insulators are furnished with one or more skirts or sheds, the object of which is to protect some part of the porcelain surface from rain and dust The size and disposition of these is largely a matter of the designer's taste, the common point in all designs being to ensure that even when all upper surfaces are wet (and, being so, are considered to be conducting surfaces) the potential difference through air from shed to shed shall be considerably below the disruptive value of the air paths

In Fig 10 are shown several modern insulator designs, all of which are for practically the same working and test voltages and are drawn to the same scale The "delta" pattern is a very widely used Continental design of German origin, but to-day it is hardly possible to assign definite nationality to the various designs as could be done a few years ago

Attention is drawn to the insulator of "flow-line" design This was originally designed by C L Fortescue, who conceived the idea of shaping the body of the porcelain to conform to the lines of flow of the electrostatic field and the upper surface to lie on zones of equipotential By doing this he contrived to bring the wet and dry flash-over figures much nearer together, since wetting the surfaces did not alter the dielectric flux distribution The big variation in the size of the

insulators shown is due almost entirely to the field distribution obtained

In passing, it may also be noted how all these multi-shed insulators are made of many separate pieces of

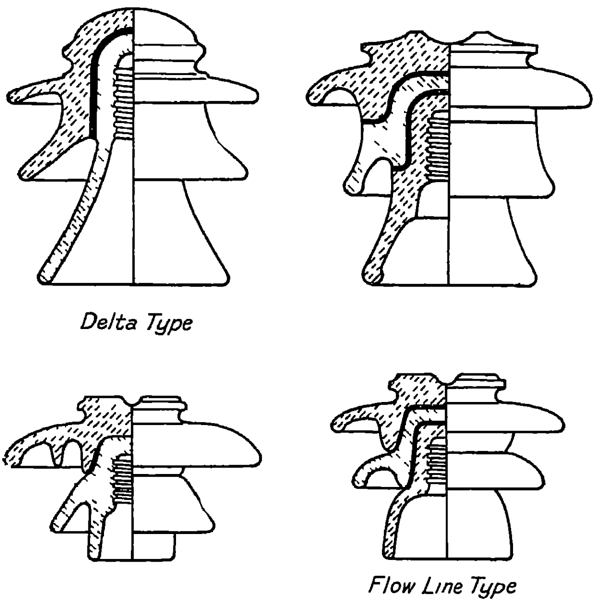


FIG 10 TYPICAL SHAPES OF MODERN 50 kV PIN INSULATORS

porcelain cemented together The greatest thickness is required from pin opening to head, so as to resist puncture under the full voltage, whereas each shed can only be subject to some lower stress, according to the voltage gradient attained The use of separate pieces enables each to be of more uniform thickness, and thus capable of being vitrified uniformly throughout The cement used is generally something of the

Portland class, and, although it has a definite electric strength of its own, yet it functions in a measure as the plate of a condenser in which the porcelain is the dielectric and gives control of the voltage gradient through the body of the completed unit

Outdoor Post Insulators, over 60 kV. The pin type of insulator ceases to be an economical design, even

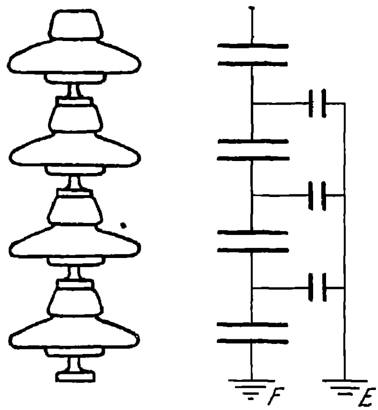


FIG 11 CAPACITY CIRCUITS OF MULTI-SHED OUTDOOR POST INSULATOR

for line construction, at about 60 kV As is known on transmission lines above this pressure, the suspension pattern of insulator is now adopted universally and, indeed, it is extending its field to the lower pressures also The earliest designs of rigid support for outdoor apparatus were mere adaptations of the suspension insulator design, the fitting which provided the flexibility being replaced by a flanged one which was bolted to its neighbours

The arrangement is obviously a series of condensers which early in this section was shown to be desirable The case is not quite so simple, however, because the

effective capacities are not only those between adjacent metal fittings, but also from each fitting independently, to ground, through the air The equivalent circuits are, therefore, actually as in Fig 11, and result in an uneven distribution of potential over the several units In Fig 12 is shown a series of curves taken from the

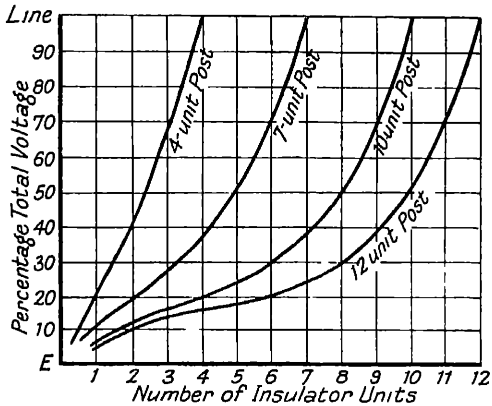


FIG 12 VOLTAGE DISTRIBUTION ACROSS MULTI-SHED OUTDOOR POST INSULATOR

author's *Choice of Switchgear* (Blackie & Son) indicating just how widely the actual potential distribution differs from the ideal The shape of these curves varies markedly with humidity even during the "dry" test and, as will be expected, the voltage distribution is much more uniform under rain conditions The actual value of voltage across the string also affects the percentage distribution across each unit

In some cases the areas of the several metal fittings throughout a post have been varied, so as to restore the desired uniform gradient, but this, of course, does away with all semblance of standardization, and vastly

increases the cost of spares and the difficulties of replacement

Not only did these designs suffer from electrical disadvantages They proved mechanically poor, even when porcelain and metal parts, much heavier than the corresponding suspension insulator parts, were used

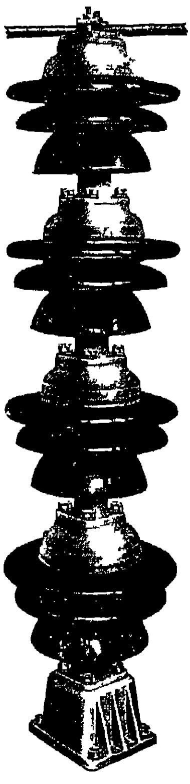


FIG 13
MODERN HIGH VOLTAGE POST INSULATOR

It will have been observed from Fig 14, that uniform distribution is more nearly approached the fewer the insulator units employed This fact led to the use of a few units, patterned after the pin insulators, and mounted rigidly one above the other as in Fig 13, which shows a modern 132 kV insulator, such as is being used on the British "grid" system With such a design, five insulator units would suffice for 220 kV working pressure, the highest voltage at present in commercial use Posts constructed on this principle would to-day be applied for all working pressures over 60 kV, and would be employed on indoor installations as well as outdoors

Compound Through Insulators. Porcelain is the preferred material for insulators in air, on account of its being non-hygroscopic, easily cleaned, damageable only by really rough treatment, and cheap It has been shown, however, that its unit electric strength falls with increasing thickness, and that there are grave

manufacturing difficulties in making pieces with very thick walls It is, consequently, common practice to make up through or bushing insulators with a porcelain outer shell enclosing some other dielectric, which may be one of many available materials Such insulators are termed " compound " insulators, as distinct from those built with only one class of dielectric, which are called " bulk " insulators

Fig 14 may be taken as typical of this class of " compound " insulators To the conductor is applied a close wrap of micarta, micanite, or empire cloth The whole thing is threaded into a porcelain shell, and the intermediate space is filled up with paraffin wax or a bitumastic compound, poured hot Adequate space for expansion during the normal working temperature cycle is, of course, left at the top end If the outer shell is provided with rain sheds, this type of bushing can be used on outdoor apparatus

The potential gradient over the surface of the insulator is that due to the porcelain profile and to the shape of the metal fittings associated at the ends and at the intermediate mounting flange The gradient through the dielectrics, from conductor to earthed mounting flange, depends mainly on the diameters of each dielectric and on their several specific inductive capacities The designer must exercise care to ensure that in each case the voltage across the dielectric bears the same relation to the breakdown voltage to be expected for the selected thickness of that dielectric, or, in other words, to ensure that there is a uniform factor of safety in all sections of insulating material It is very easily possible by " adding more insulation " to throw so much greater voltage on to some other part of the insulating system, as to cause breakdown there

Oil-filled Insulators. Strictly speaking, the oil-filled insulator is a compound design, but the practice of the

day has put it in a distinct class of its own In Fig 15 is shown an insulator of this type, as built by one of the leading American porcelain specialists The broad

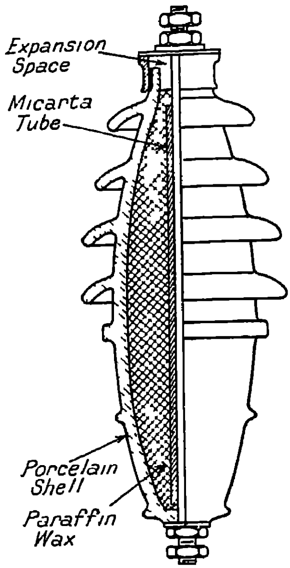


FIG 14 SOLID FILLED COMPOUND INSULATOR

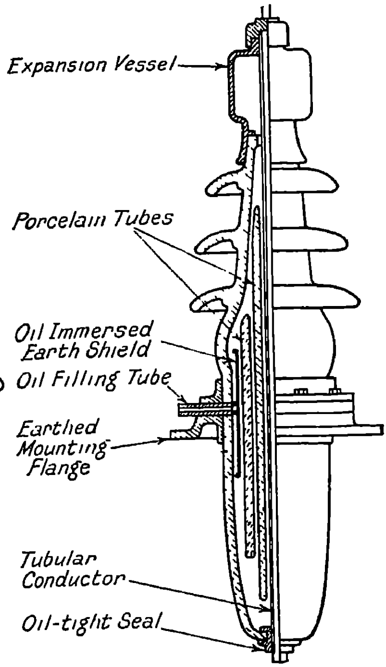


FIG 15 OIL-FILLED BUSHING WITH PORCELAIN INNER TUBES

idea is the same as in the previous illustration, save that the porcelain shell encloses a series of concentric porcelain tubes, and that the interior is then filled with ordinary switch oil Preservation of the lower oil-tight joint proved a great difficulty for many years, but this is now a thing of the past, since the introduction of

cements which expand slightly on setting and the use of treated cork gaskets An upper sight glass (which also acts as a conservator vessel) is still an inevitable fitting, but really is only needed in the event of a porcelain casing developing a crack, and thus allowing the oil to escape The surface of oil exposed to the air is so small that no trouble occurs in practice due to moisture absorption Insulators for use in very humid climates have sometimes been fitted with air-drying breathers, but experience has proved them unnecessary It is claimed that by using oil as a filler the bushing automatically reseals after puncture, as the oil flows into the holes formed in the spacing cylinders This may be so, but a properly designed bushing should flash-over before puncturing at all If a plain shell were filled with oil, there would always be a risk of impurities in the latter lining up along the electro-static stress lines, thus forming a chain conducive to puncture at low voltage, hence the cylinders of solid dielectric which prevent such chains becoming continuous

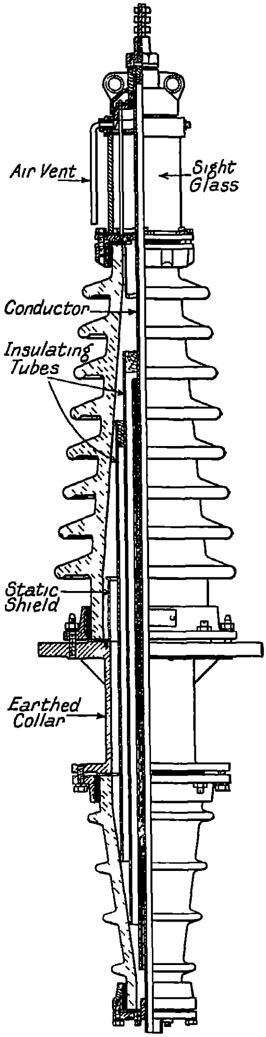


FIG 16 OIL-FILLED BUSHING

The General Electric Co of America are responsible for the design of the oil-filled bushing shown in Fig 16, which bushing is doubtless more widely used than all the other compound insulators together, since to-day the design is used by all the firms associated with the General Electric organization In this form, the inner cylinders are made from micarta or pressboard, which while serving as a solid barrier across the oilpath, also has a very high electric strength of its own The conductor wrap is often a special cloth dielectric, which also has high breakdown value The combination of these materials has permitted the diameter at mounting flange to be reduced to a much lower figure than in any other arrangement in this class

It will be observed that in this design, the porcelain plays no part other than that of oil container, with a surface suitably shaped to give a satisfactory wet flash-over figure At the mounting flange, to which a puncture would have to strike, the dielectrics are only oil and fibrous materials The length of this earthed flange plays a very definite part in ensuring satisfactory flash-over performance at the lower, under-oil, end as will be explained in detail under a succeeding heading

Condenser Bushings. The condenser bushing is the only design in which the potential gradient is definitely controlled both through the thickness of dielectric and over its surface Essentially, it consists of a series of micarta wraps, applied directly on to the conductor, and separated one from the other by layers of tinfoil of lengths decreasing from the middle outwards much as indicated in an exaggerated manner in Fig 17 Each section between adjacent layers of foil thus forms a condenser If the capacities are the same, the voltage from layer to layer will be uniform, and there will be the same voltage difference between the edges of neighbouring foil layers over the surface

In a practical construction some modifications are necessary, and in Fig 18 are shown sectional views through actual bushings as made by Metropolitan-Vickers Co in Manchester If the edges of tinfoil were exposed in the air, as indicated in Fig 17, they would form concentrating points for the electrostatic field, and glow discharge would originate there These edges are, therefore, buried in a dielectric, which, in the shorter bushings, made from sheet paper, is merely the micarta itself, as indicated in the right-hand illustration (Fig 18) Long bushings are wrapped with strip paper applied spirally, and with joints broken on successive layers In these, the foil edges at the air ends are sealed with bitumastic compound filled in between the bushing and the outer porcelain weather casing, while the foil at the ends which project into the oil tank is prevented from originating brush discharge by the oil itself

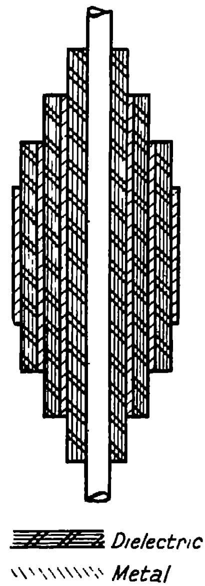


FIG 17
PRINCIPLE OF CONDENSER BUSHING

A wire wrap is used in place of foil for the last plate of the series of condensers, so as to give a suitable surface on to which the earthed mounting flange can be connected and cemented Compare the length of this wire banding, with that of the mounting flange in the General Electric oil-filled bushing

Except for quite low voltages, the inner conductor is always tubular Primarily, this is because for any given voltage between steps, quality of micarta and

for test The majority of the standardizing institutions of the world also have recorded their ideas, from all of which emerges the fact that agreement has not yet been reached At the moment of writing the British Engineering Standards Association has committees again considering the problem, and endeavouring to reach a common basis of agreement with their colleagues abroad It would be unwise, therefore, to confuse matters by putting forward herein any figures, however tentative, and the reader is referred instead to the existing B S S 137/1922 and to the B S S dealing respectively with line insulators, post insulators, and bushing insulators, which will be forthcoming in due course

Arcing Horns. The ratio between wet and dry flash-over values is not, and cannot be, constant for insulators of different design The flash-over values are not constant even for the same design, in fact It is desirable, nevertheless, in a power system, to ensure that if trouble occurs, it shall do so if possible at the point where it is most easily rectified To this end, many engineers arrange to include on their lines near the stations, a few insulators which are known to have a lower flash-over voltage than the rest, either on the line or in the station itself Because of the varying wet/dry flash-over ratio, this device alone is not entirely reliable, and, since there is no particular point in having a higher dry than wet flash-over, resource is commonly had to arcing horns These are metal extensions fixed to the line and earth fittings of the insulators, so shaped and located that when arc-over occurs it will be between the horns, and not over the surface of the insulator

Between pointed electrodes, or spheres of diameter small in comparison with the spacing, there is no difference between the wet and dry flash-over figures As

the diameter of electrodes is increased, differences appear and become more and more marked On the voltages now in use, it is possible to secure a very great measure of independence of these factors, by using horns with electrodes of the order of $\frac{1}{2}$ in or 1 in radius

Such relative independence secured, it becomes practical politics to arrange for and expect line insulators to flash-over at the lowest voltage, post insulators in the substation to go at, say, 15 per cent higher pressure, and the expensive bushings in transformers and oil switches to flash-over at the highest figure

Let it be repeated, however, arcing horns have the effect of making the lower, wet flash-over figure the standard for a given insulator, and of bringing the dry flash-over down nearer to the wet figure Emphasis is made, not because the writer disapproves the use of arcing horns—on the contrary—but because there is frequent misunderstanding of their effect

Altitude. Air density has a marked effect on the flash-over value of an insulator, and thus where apparatus is being installed on high eminences, it is necessary to use insulators with a longer flash-over path in air than would be necessary at or near sea level In usual practice, precautions of this kind are not necessary if the altitude is less than 3000 ft above sea level The variation in air density with altitude is given by the curve, Fig 19 The necessary flash-over path for any voltage at any altitude is closely approximated by dividing the equivalent sea level length by the air density

Fog and Mist. Dirt on the sheds of an insulator, such as may be expected to settle there in open country, is rarely a source of special trouble Most of it is washed off by rain and it covers only the upper surfaces, so that even while present the effect is merely that the

the system voltage is relatively low, it is usually a practical possibility so to arrange contact design, speed of opening, etc., as to insert a sufficient resistance in the arc path to prevent reformation after the first or at most, second, half cycle. The period of gas formation is, consequently, short—0·01 to 0·02 sec.—and the process is somewhat in the nature of a slow explosion. With system pressures such as are used for transmission to-day, the voltage available to restrike the arc, after the current wave has passed through zero, is so great that there is no hope (with our present designing knowledge) of preventing reformation. With the most successful modern circuit breakers, the arcing time on 80 kV may be of the order of 0·1 sec., and on our British maximum of 132 kV it may last for 0·15 sec., or even longer.

As the resistance of the arc path is a function of its length, there is definite advantage in increasing the length as rapidly as possible, even if this can only be accomplished through part of the necessary stroke, as the total arc energy, in any case, will be reduced. Special devices for accelerating the break are, therefore, incorporated in most circuit breakers for very high-voltage work.

For a given breaking duty, the pressures transmitted to the tank walls are less as the voltage increases, partly because the speed of gas generation is lower, but chiefly because the tanks are of necessity farther away from the arc contacts—the centres of gas generation. Relatively light tanks, then, are characteristic of high-voltage circuit breaker construction. Where the breaking duty is only moderate, it is sometimes possible to design the tank only so that it will not deform under the weight of contained oil.

Some cushioning space is necessary above oil level in all makes of circuit breaker. Hence, the insulating

bushings extend, below their flanges, through both air and oil On a previous page, emphasis was laid on securing a safe voltage gradient through each of several dielectrics which may be in series This multiplicity of dielectrics might obtain with the electrostatic field surrounding the lower end of the bushing. It is quite possible to proportion the path length through oil and air, so that the latter will not be overstressed, but *the actual oil level is in the operator's hands, and beyond the definite control of the designer* A variation in the oil level might result in a brush discharge through the altered air path, and if by chance an explosive mixture occupies the air space, disaster might follow This is no mere academic speculation The thing has been known to occur and is easily reproduced experimentally The only safe course is to take the earthed metal of the bushing flange right down into the oil, at least as far as the bottom of the gauge glass provided in the tank This makes practically certain that under all conditions the whole path over the lower surface of the bushing will be through oil

The large clearances necessary through air and under oil result in oil tanks which become too unwieldy to be lowered in the conventional manner, where the pressure exceeds about 80 kV These very big tanks are, therefore, located permanently in position on the ground, and a manhole must be provided in the top for access during erection and maintenance Such ready access is quite important, though not always easy to secure without unduly cramping the lifting mechanism

Manual control through a lever system is possible on breakers up to, say, 50 kV, above which electrical control, either by solenoid or motor, is universal, on account of the weights to be moved

Since practically all modern super-generating switchgear is located out of doors, if not of the metal-clad

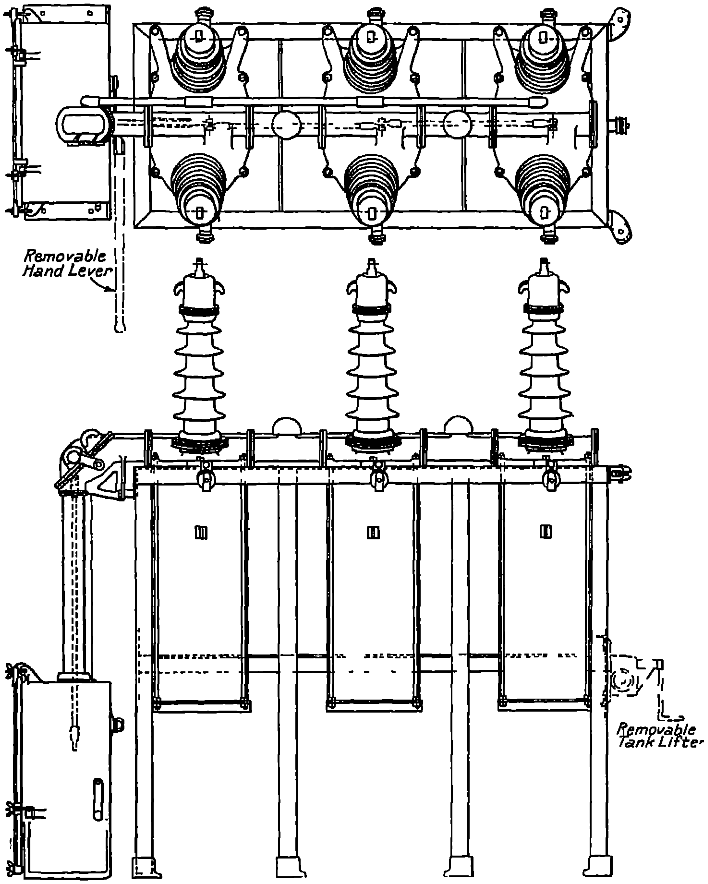


Fig 20 Metropolitan-Vickers 50 kV Oil Circuit Breaker

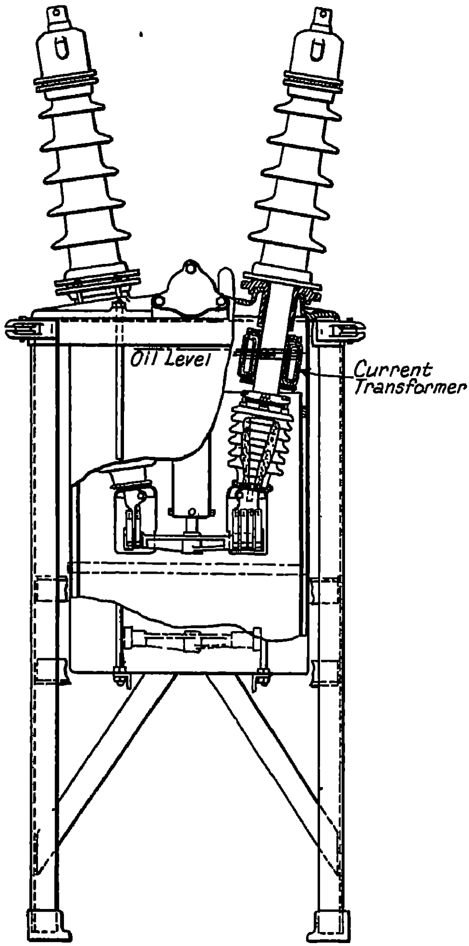


FIG 20A ENLARGED END VIEW OF CIRCUIT BREAKER SHOWN IN FIG 20

pattern, it is reasonable to generalize and say that all circuit breakers, such as are treated in this manual, would be remote electrically operated

To give a proper idea of British practice, typical examples of the product of the leading makers of high voltage, open type, circuit breakers, are illustrated and discussed below

Metropolitan-Vickers Co. In Fig 20 is shown the standard circuit breaker for 50 kV service, where the required rupturing capacity is not abnormal Three separate pole units are employed, the welded steel tanks being suspended beneath cast steel top plates The three poles are carried from a section steel framework at a sufficient height to permit the tanks to be lowered for contact inspection To facilitate this a set of pulleys is permanently placed to take a wire rope from a portable tank lifting winch At one end of the framework is a weatherproof casing enclosing the operating solenoids, closing contactor, and terminal board for the small wiring

The tanks are lined, the space between lining and tank being appreciably greater than is employed on circuit breakers for a less system voltage The contacts are of the well-known wedge type, but do not incorporate any special quick-breaking device, since in this field of voltage, it is found possible to secure adequate speed of break with accelerating springs located in the mechanism housings The moving element is suspended by a tubular micarta lifting rod, which passes through a second micarta tube serving as a guide The whole parallel motion lifting mechanism is carried on a removable bracket casting beneath the top plates and between the earthed portions of the bushings In this position it does not reduce the possible clearances to live metal in air or in oil

The condenser bushings are of sheet-wound micarta,

porcelain housed at the upper end when used outside, but otherwise left uncovered The outer banding wire is carried well below oil level Under oil there is a porcelain shield to protect the exposed edges of the condenser foils The corrugations on the porcelain are intended to break up any possible direct stream of water drops which might condense inside the top The bushing mounting flange is carried on a rocking seating to facilitate adjustment of the contact position

Fastened to the underside of the top casting, and surrounding the bushings, are placed the ring-type current transformers The condenser type of terminal possesses marked advantage here, in that it is smaller in diameter than any other design Hence, the ratio curve of the current transformer can be kept within reasonable limits of accuracy down to a much lower primary current

Fig 21 shows a circuit breaker designed for 154 kV service, where the interrupting duty may be as high as 1,500,000 kVA The tanks and top plate are built as a single unit, from steel plates rolled or pressed to shape and welded together No lining is used in this design, the clearances from live metal to side of tank being increased to compensate for its omission The general construction and location of lifting mechanism follow the same lines as that for 50 kV service

The quantity of oil necessary for a breaker of this size makes it impossible to move the tanks for contact inspection, so that floor mounting is resorted to, and a manhole provided for access To prevent sweating, the bottom is raised slightly and ventilating openings are provided to enable painting to be done when necessary Attention is drawn to the jacking and slinging lugs used in erection and also to the concentric ribs welded inside the dished tank bottom, to give a grip for the feet when working inside

The pull rods coupling the three units pass through large pipes for weather protection To prevent gas formed in one tank from passing to its neighbours, these outer pipes do not terminate in the air space above the oil, but in a separate box through which a rotating shaft transmits movement to the lifting mechanism This gives a perfectly gas and flame-tight construction

The main contacts are of the wedge pattern, but supplementary quick-breaking arc contacts are used as well A positive catch which is not subjected to electrical wear and which cannot let go till the main contacts have separated several inches, is incorporated, in addition to using powerful accelerating springs in the magnet housing The details of this will be clear from Fig 22, which shows the contacts and corona shield in shadow

The patented contact and bushing mounting is noteworthy A porcelain sleeve is suspended from a flange casting resting on the cover opening and at the lower end carries the fixed contacts Within the flange casting the bushing current transformers are supported The condenser bushing itself is carried on a second flange, which rests on the cover of that carrying the porcelain sleeve The porcelain acts as a shield for the exposed micarta surfaces and is filled with oil independently of that in the tank proper, so that carbon or other impurities in the latter cannot possibly get near the edges of tinfoil A flexible conductor is fixed to the contact block, taken through the tube on which the bushing is wound, and connected directly to the top metal fitting on the bushing It is thus possible to set up all contacts in the factory and yet ship the bushings packed separately The gain in working time is more marked if it is ever necessary to change a bushing on site, since with all other designs changing

bushings necessitates removing the oil so that contacts can again be set up, and, of course, the precise location of the bushing is a matter of much greater importance

In very important stations it is sometimes the practice to run permanent oil filling and draining buspipes,

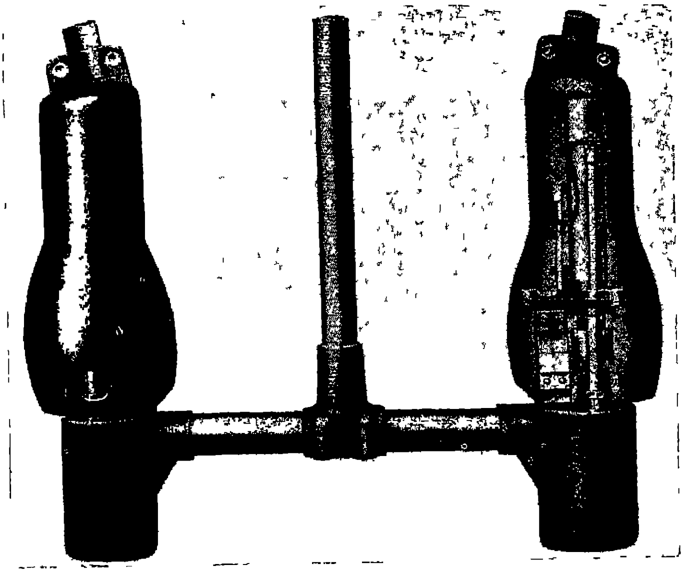


FIG 22 SNAP BREAK CONTACT OF METROPOLITAN-VICKERS 154 kV CIRCUIT BREAKER

which connect to the large valve shown A small pet cock is placed next this valve so that oil may be drawn off in small quantities for test

Ferguson Pailin, Ltd. In Fig 23 is shown this Company's standard circuit breaker for 37 kV mounted upon the pipe framework used in installation. The three poles are built up as entirely separate units, and

rather unusually, the closing solenoid and trip mechanism are introduced between two units and do not drive from the end, as is usual. Apparently, the object

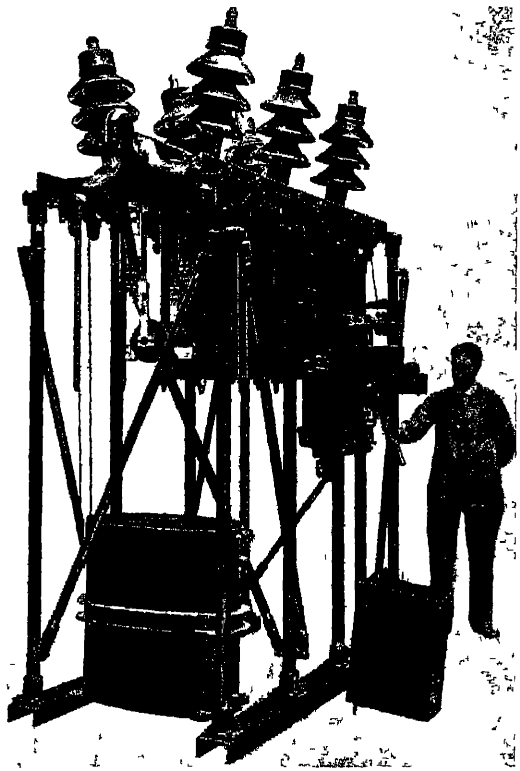


FIG 23 FERGUSON PAILIN 37 KV OIL CIRCUIT BREAKER

is to reduce the twist on the operating shaft which runs through all three pole units A proper bearing for this shaft in the sides of each top casting serves to prevent gas passing from unit to unit

It will be noted from the illustration that the moving contacts are carried on an insulated crosshead, which in turn is raised or lowered by steel links at the sides Guide rods dependent from the top casting serve to constrain the crosshead along a truly vertical path and, at the same time support the accelerating springs, clearly visible in the illustration The design is one which puts the insulation in compression only, but as micarta is used for the purpose, there is no marked gain in safety The reason for placing the insulation in this manner is, no doubt, because thereby parallel motion links under the top casting are avoided, leaving greater space for ring-type current transformers

The main and arcing contacts are of wedge pattern, and the terminal insulators of the condenser type, protected with a single-piece porcelain weather shield The elliptical tank sides are solid drawn steel, with a dished bottom welded on A channel steel band is welded round the tank at the point opposite the arc contacts, where the maximum shock due to gas generation is felt

In Figs 24 and 25 is illustrated the highest voltage circuit breaker built for frame mounting It will be apparent that the general lines of construction are not unlike these for the 37 kV unit, just noted, due allowance being made for the greater clearance necessary A circular tank gives that extra clearance needed to retain the insulated crosshead construction at higher voltages

In this, and the higher voltage designs, both the crosshead itself and the bridging contact arm are insulated with bakelite micarta This is one of those cases referred to on a previous page where two systems of dielectric are placed in series The clamp holding the one to the other forms the intermediate conductor plate The design is an extremely difficult one to calculate so as to get a proper distribution of voltage,

although, of course, the arrangement is perfectly sound where this point has been checked up experimentally

The right-hand view in Fig 25 shows clearly the scissor-like arrangement of levers which balances the

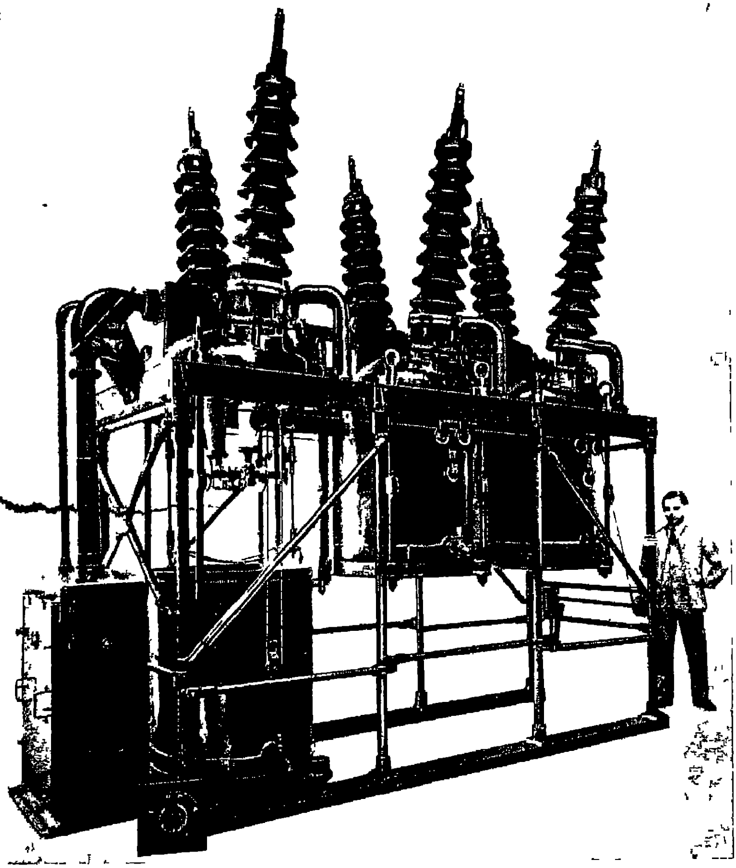


FIG 24 FERGUSON PAILIN 88 kV OIL CIRCUIT BREAKER

lifting forces equally on both ends of the insulated crosshead and also the long sleeves which guide the crosshead on the side rods Attention is drawn to the manner in which the reciprocating movement of the operating rod is changed to a rotary one at the angle of the first cranked levers The way shaft for these

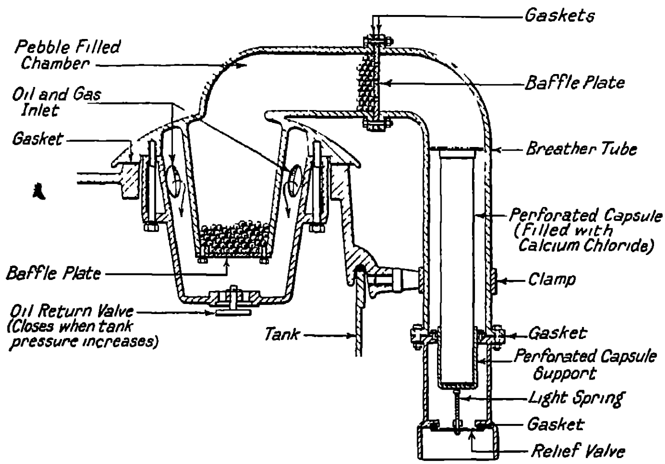


FIG 26 GAS VENT FOR FERGUSON PAILIN CIRCUIT BREAKERS

levers passes through the sides of a cast pocket attached under the top In this way gas inside the switch is prevented from escaping except via the proper vent

The venting arrangements merit some special attention In Fig 26 is given a sectional drawing of this device Oil and gas enter side ports in the outer shell, whence the gas is constrained to pass upward through a passage filled with marbles or small pebbles These oppose the passage of oil, while allowing practically free egress for gas The trapped oil drips back into the oil tank, while gaseous products pass out through

a lightly-loaded relief valve The venting device is also fitted with a chloride breather, a luxury deemed unnecessary by most makers

The very high-voltage, floor-mounted design is typified by Fig 27 Here, again, the insulated crosshead

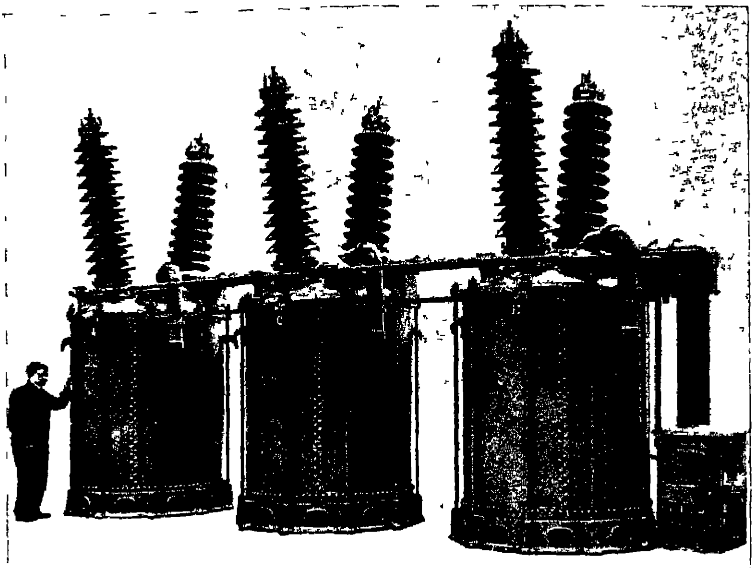


Fig 27 Ferguson Pailin 132 kV Oil Circuit Breaker

is adhered to, as are all the main features mentioned previously The circuit breaker top is of cast steel, and is held in position by long steel bolts anchored in the base casting The separable top is a feature of value only during manufacture, since on site it is hardly practicable to lift so large and heavy a piece during ordinary maintenance work For the latter a manhole is provided

Quick break contacts are fitted, these depending on a double catch, spring controlled, which engages a

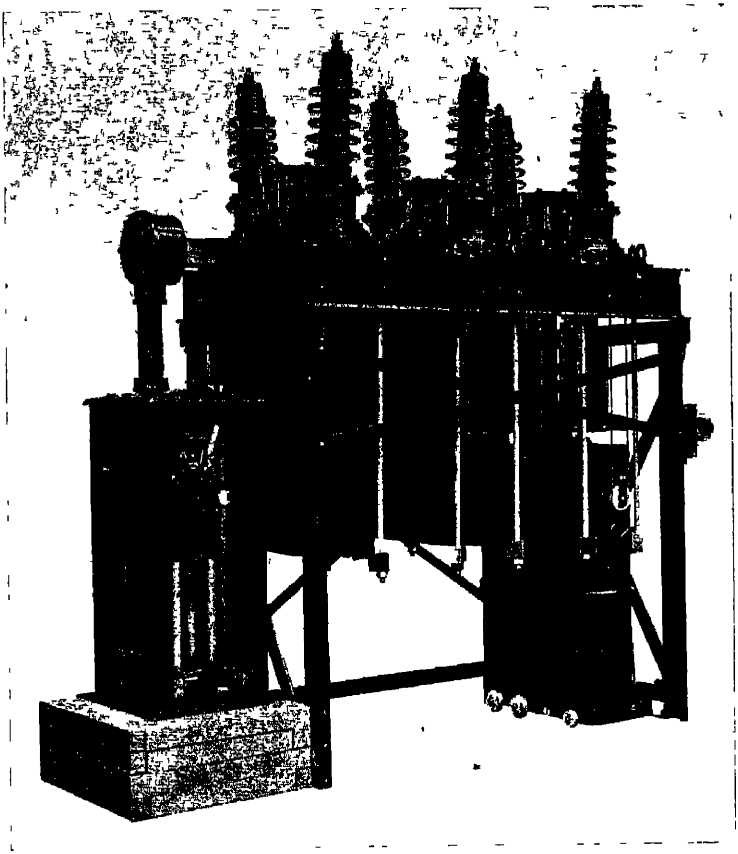


FIG 28 B T -H 33 kV OIL CIRCUIT BREAKER

groove at the end of each arcing contact finger The main contact wedge travels several inches before this

snap break reaches its full extension, the actual break occurring when the crosshead has already acquired considerable speed

British Thomson-Houston Co., Ltd. The apparatus built by this Company covers the same field as that already reviewed The lower voltage range is typified by Fig 28, which shows the standard frame mounted 33 kV unit Here, again, three entirely separate pole units are employed, these being coupled by a torsion shaft running through the top castings Operation may be by solenoid (as shown) or by means of motor-driven fly-balls in those positions where only alternating current is available for auxiliary service

As usual, the bushings pass through ring-type current transformers carried on the circuit breaker top

The contacts are of the wedge pattern where the breaking duty is moderate, but when high interrupting capacity is necessary the explosion pot, referred to in some detail later, is added

Fig 29 is a sectional view through the 88 kV circuit breaker, which the makers regard as being on the border line in the matter of weight, and are prepared to mount on the floor or on a framework, according to the users' needs This drawing shows excellently the broad lines of standard construction The tank is cylindrical and of welded steel plate, with dished bottom A cast steel top plate, fastened to the tank by numerous short bolts, carries the bushings and contact lifting mechanism

The parallel motion link gear in each pole is coupled to its neighbours by a pull rod which travels in a gas-tight casing, separate from the circuit breaker interior The moving contacts are carried by a micarta rod, lateral movement of which is limited by a V-shaped guide, made of oil impregnated wood and dependent from the top cover

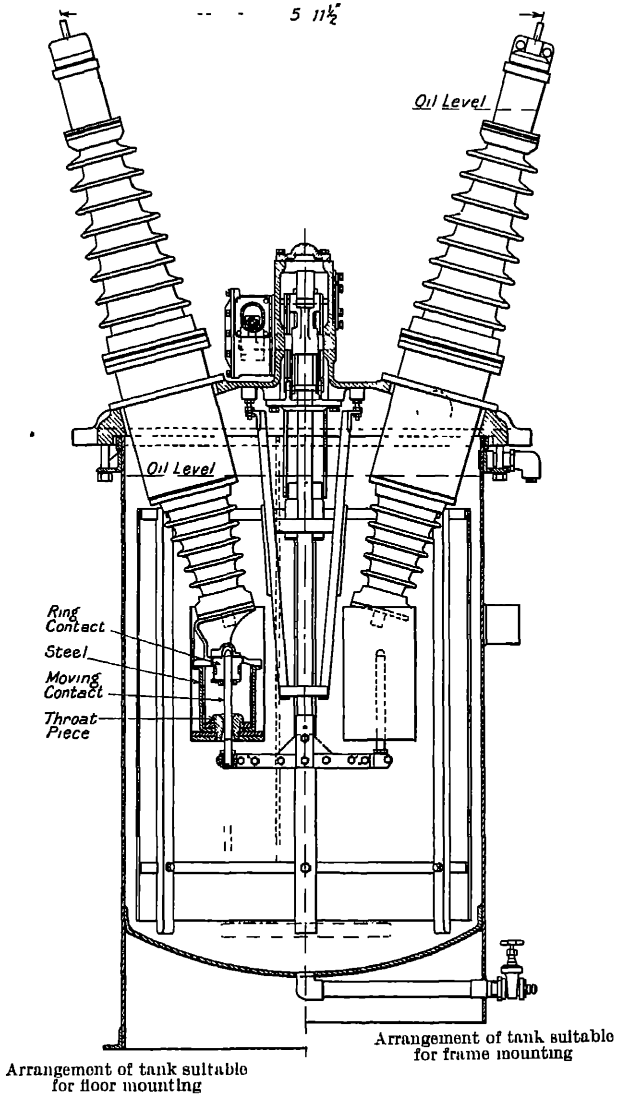


FIG 29 B T -H 88 kV OIL CIRCUIT BREAKER

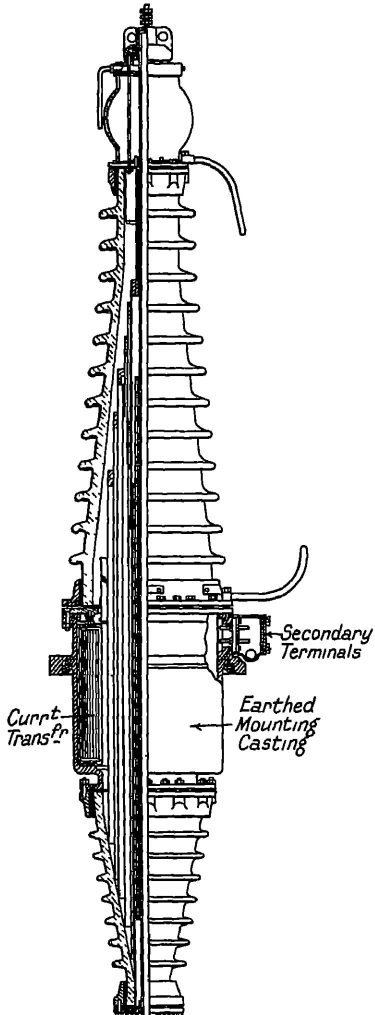


FIG 30 B T -H OIL-FILLED BUSHING WITH CURRENT TRANSFORMER

The explosion pot type of contact is shown in section on the left-hand terminal A spring-mounted, ring-shaped contact is located in the upper part of a strong steel cylinder, all surfaces of which are heavily insulated The moving contact is a long brass or copper rod, which passes up through the insulated throat piece and enters the ring contact As the circuit breaker opens, the arc is first drawn inside the steel cylinder (which naturally is filled with oil) and gas is liberated therein Its egress is practically blocked by the moving rod, however, on which the confined gas exerts extremely high pressure, ejecting it rapidly from the throat piece The device then acts as a gas-spring, giving a quick break action, the acceleration varying with the current interrupted The arc is not

necessarily quenched within the explosion pot, although at moderately high voltages this does occur

The bushings used in this and other circuit breakers for the higher voltages are of the oil-filled type and, as will be seen from Fig 30, an enlargement of the

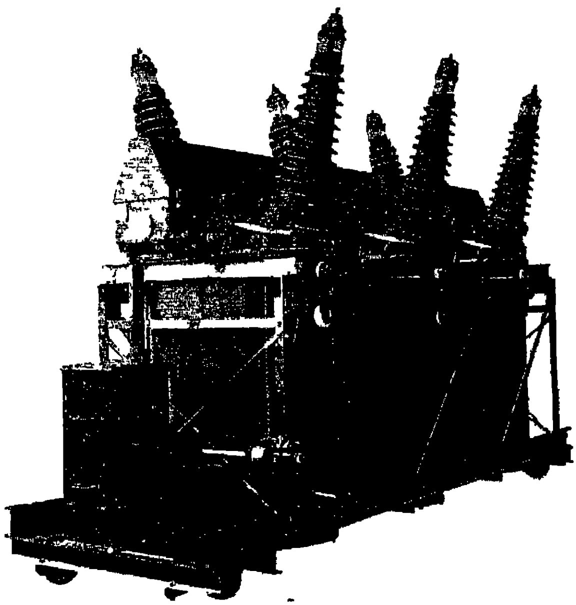


FIG 31 B T -H 110 kV OIL CIRCUIT BREAKER

earthed central flange ingeniously provides accommodation for the current transformer, the diameter of which by this means is kept down nearly to that which could fit over a corresponding condenser type terminal, while the necessary opening in the circuit breaker top is not enlarged at all It is, of course, arguable that

kV	Fig	Breaking capacity to suit							
		Average requirements				Extra large requirements			
		A	*B*	*C*	*D*	*A*	*B*	*C*	*D*
		ft in	ft in	ft in	ft in	ft in	ft in	ft in	ft in
22	1	9 3	3 4	8 9	2 3	—	—	—	—
37	1	10 3	4 –	9 10	2 6	14 9	4 6	11 9	4 –
50	1	13 5	4 3	12 –	4 –	15 4	4 6	13 11	4 0
73	1	15 –	4 10	12 7	4 3	18 4	5 7	16 11	4 11
88	1 or 2	15 –	4 10	12 7	4 3	20 1	5 7	16 11	5 6
110	2	25 –	6 –	15 6	8 –	—	—	—	—
132	2	27 –	7 –	16 5	9 –	—	—	—	—
154	2	27 –	7 –	17 7	9 –	—	—	—	—

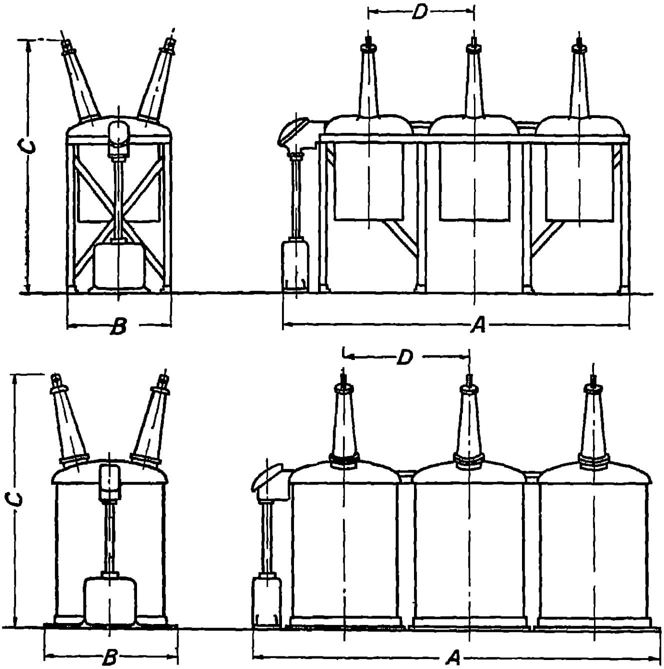


Fig 32 Key Sketch for Table of Dimensions

in such a location the current transformers are rather inaccessible, but access in practice is not often necessary

Fig 31 illustrates an unusual form of mounting, the complete circuit breaker with its solenoid being slung on a low truck, which can be rolled over a pit, and the tanks there lowered by the self-contained winch gear, when necessary to inspect contacts This arrangement gives all the access facilities necessary, since the contacts on very high voltage circuit breakers suffer damage less frequently than those on generating voltage apparatus, but, at the same time, the structure height is not unduly increased

Dimensions. Frequently it is necessary for supply authorities' engineers to form some preliminary idea of space requirements, while matters are yet in too vague a state to ask for manufacturers' definite proposals To assist such work the table facing has been prepared The dimensions given therein are compiled from the data of the four British firms who specialize in this class of manufacture, and in each case the largest dimension has been tabulated Rough drawings based on these figures will, therefore, certainly show sufficient space to accommodate apparatus built by any British maker

LIGHTNING ARRESTERS

It is doubtful if any terms are more loosely used by engineers than "lightning" and "lightning arresters" The former is made to embrace anything from a mild switching surge up to a direct stroke of lightning occurring during a tropical storm, while there are sold under the name of lightning arrester, devices which would probably be blown to pieces by any impulse at treble system voltage, and devices which can be relied upon to clear the system from anything short of lightning striking the apparatus itself There

is no known device which can be guaranteed 100 per cent effective.

Money spent on lightning arresters can only be regarded as capitalized insurance premiums The sum it is justifiable to spend depends on the value of the plant to be protected, the commercial value of continuity of service, and on the probability of lightning occurring The latter consideration is important The writer knows at least one case of expensive arresters being installed in a place where lightning has never been known The first step, therefore, is to consider fully and carefully all of these factors

Switching operations usually give rise to over-potential surges, if the associated system has any great reactance and capacity The frequency and amplitude of such surges both are higher than that of the supply, but, as a general thing, the over-potential is not great enough to damage connected apparatus Occasionally, it will happen that the line characteristics are of values tending to resonance at particular points The condition naturally makes itself obvious quite soon, and suitable protective gear can then be installed at these nodal points To install surge arresters on all feeders right at the outset is an unwarranted extravagance

It has already been stated that nothing has yet been devised which could be relied upon absolutely if lightning struck the line close to it A direct strike would raise the potential locally so high as immediately to shatter adjacent insulators, and thus discharge to ground without traversing the line to any extent. The gambling chances of lightning striking the line or outdoor switching apparatus close up to the arrester are so slight that disability to deal with such occurrences is not in itself a reason for at once deciding against installation of protective equipment

Induction by cloud-to-cloud discharge is possible, but

not very probable The most common cause of over-potential due to atmospheric conditions is as follows A cloud which is electrostatically charged will induce a corresponding and opposite charge in the line beneath If the cloud discharges (by lightning stroke), the bound charge in the line is released and progresses in both directions along the line as a high potential wave with very steep wave-front The chances are in favour of this particular class of over-voltage doing most damage to transformer and connected apparatus, since it moves rather in the form of a tidal wave, unidirectionally, and may easily pass insulators without causing them to flash-over, only causing trouble when it meets the reactance of a switching or transformer station Here it gets reflected back, and possibly becomes oscillatory, and of even increased magnitude In districts where lightning storms are prevalent, protective gear is usually necessary to cope with over-potential due to this cause

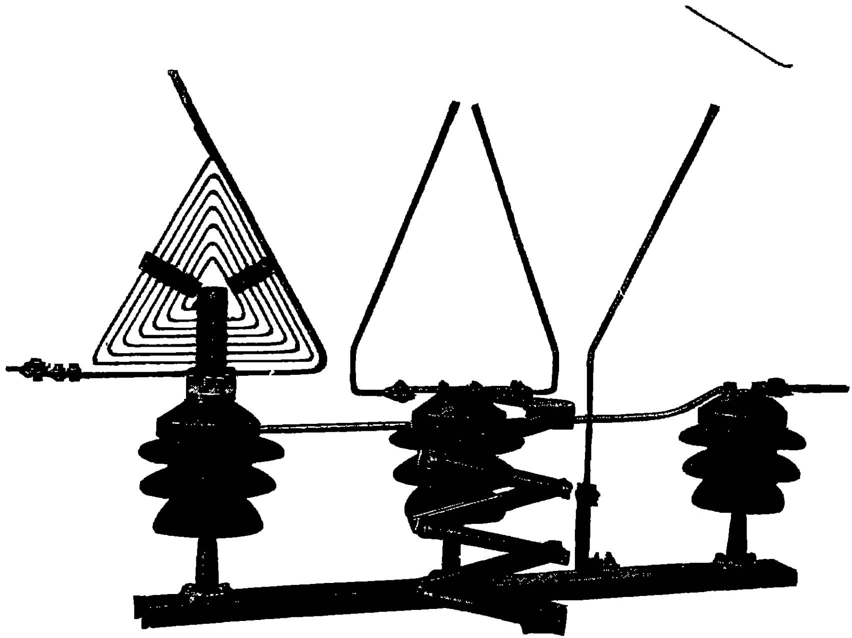
There comes, also, a consideration of the type of line construction adopted, and the system voltage Where steel poles or towers are used, standing on soil which gives good electrical connection with earth, and when an overhead earth wire is run from pole to pole, this in itself forms a very effective protective arrangement When the system voltage is high, although the insulator factor of safety may be no greater than on a low-voltage line, the actual margin of voltage rise necessary to produce flash-over is greater The amplitude of the cloud-induced wave is not affected by the system voltage, however, and, consequently, troubles are to be expected much more frequently on the lower voltage lines As a fact, a great number of the systems at 100 kV upwards in all parts of the world are to-day operated without any lightning protective devices other than the overhead earthed wire above the lines

The effect of " arrester density " has no direct bearing

when dealing only with super-generating voltage apparatus, but it may be mentioned in passing In certain countries even urban distribution is carried out overhead, with small transformers at frequent intervals At each transformer is installed an "arrester" of extremely limited discharge capacity Taken singly, these things are of very little practical value in protecting the transformers It has been found, however, that where a large number of them are installed in a small area, very little trouble is experienced, no doubt because of the numerous parallel paths to earth which are afforded

Horn-type Arresters. Many firms to-day build variants of the horn-type arrester which was originally designed by Siemens and Halske Essentially they are all the same, and consist of a pair of branching metal horns approaching each other at the bottom, and having in series a resistance which may be a water column, oil-immersed metal wire or rods of carbon, carborundum, or other composite material The horns are separated by an air gap of such length that a voltage of, say, 50 per cent above normal will jump across In this way, overpotentials are shunted to earth, and, provided the current is not excessive, the arc will be carried up the horns, and be ruptured when the overvoltage is relieved Experiment has shown that the limit of current is about 10 amp As a rule, the resistance value is such as to keep the current down to not more than 5 amp when system voltage is impressed The thermal capacity of the resistance element determines the frequency with which the arrester can discharge

Burke Arrester. This is a modification of the usual horn design, in which, as will be seen from Fig 33, the choke coil is incorporated, this being made of triangular "pancake" form so that one side can function also as a horn Because of the sharp bend which occurs in the coil at the air gap, high-frequency



(*Metropolitan-Vickers*)

FIG 33 "BURKE" TYPE OF HORN ARRESTER

waves tend to increase in amplitude, and for a given spill-over voltage, a larger gap can be used, a distinct advantage, especially in insect-ridden lands

The Burke design lends itself admirably to small sub-station layouts, as a study of the succeeding pages will show

Multi-gap Arrester. The multi-gap arrester also is one of the well-known designs, consisting as it does of a number of small gaps in series with a limiting resistance, a second resistance paralleling the first and also some few of the gaps This arrester usually has a discharge capacity of about 20 amp , but, although in this respect better than the horn, the construction does not lend itself to outdoor work Moreover, it is bulky and relatively expensive when built for the higher pressures

Electrolytic Arrester. This was the first arrester designed to have a really useful discharge capacity, something of the order of 1000 amp For many years it held premier place, despite the fact that it required daily attention to reform the insulating film, and that at all times it called for quite expert and careful maintenance Although there are many systems which still rely solely on this device, it is no longer regarded as a regular product The modern equivalents are the oxide film and auto-valve types, which are both much less delicate and do not call for daily attention

Oxide Film Arrester. This arrester was introduced by the General Electric Co of America in 1918 It is built up in two forms, having discharge capacities of 1000 and 250 amp respectively, applied according to the importance of the service to be protected The larger equipment is built of a number of standard unit assemblies, each of which comprises an insulating ring on each side of which is fastened a sherardized steel plate The space within the ring is thus completely boxed in The inner surfaces of the steel plates carry

a coat of insulating varnish very carefully applied to a definite thickness The interior space is filled with lead peroxide This material is quite a good conductor until it is heated, when it changes to the highly insulating red lead

If, between the steel plates, a sufficiently high voltage is applied to puncture the varnish, current will flow, but in so doing it heats the lead peroxide through which it passes and converts it to red lead, which seals the puncture, and stops the passage of current It is clearly only a matter of careful manufacture to ensure that each of these units will have a standard puncturing or critical voltage, and thus it is only a matter of assembling a suitable number in series to secure a protective device suited to any system pressure Three of these sets of units are used, a covered sphere-gap being inserted between them and the lines themselves

The form having the lesser discharge capacity is known as the pellet type, from the fact that the elements consist of pills of lead peroxide coated with varnish These are poured into an insulating tube, which has metallic plates top and bottom in contact with the pills As in the larger type, an air gap comes between one of these plates and the line In this design each pellet is a miniature of the separate units of the larger form, and it is purely a matter of experiment to find a suitable diameter and length for the container, to put sufficient pellets in series and in parallel to suit any given system voltage and required discharge capacity

Auto-valve Arrester. The auto-valve arrester was first marketed by the Westinghouse Co in 1923 A number of flat discs made of a composite resistance material are stacked one above another, each being separated from its neighbours by a very thin mica ring The resistance discs are thus in series with numerous small enclosed air gaps It is characteristic of such

gaps that above a certain voltage, a glow discharge starts and thus provides a path to ground A slight drop in pressure below this critical voltage causes the glow to cease, and interrupts current flow Local heating would instantly cause the glow to change to an

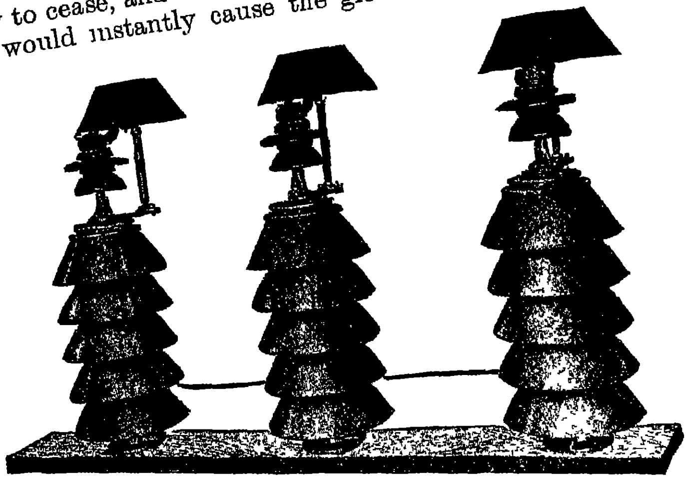
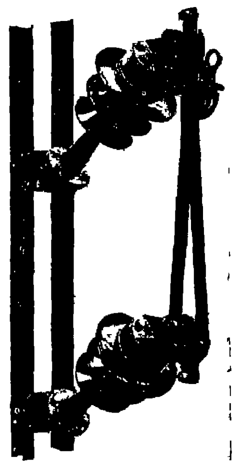


FIG 34 LARGE CAPACITY AUTO-VALVE ARRESTER FOR 25 KV

arc (which has a far lower critical voltage), and it is for this reason that resistance blocks are used, since, if these are homogeneous, and have reasonably flat surfaces, the resistance prevents current concentrating through localized paths, but forces uniform distribution over the entire exposed surface

Units of this form are assembled in sets and connected to the line through air gaps, just as in the case of the oxide film pattern For large discharge capacity service, four sets in parallel are used per circuit, the assembled equipment being shown in Fig 34

It is claimed for the auto-valve principle that the arresters have unity impulse ratio, i e are unaffected by the steepness of the surge wave-front, while the presence of a solid dielectric in the varnish film of the oxide film type must necessarily make the impulse ratio higher than unity, so that operation is a trifle slower on steep-fronted waves The present writer has no laboratory experience to confirm or refute this claim It is a fact, however, that the two types are undoubtedly the best devices yet available for giving protection against over-potential troubles



(*Ferguson Pailin*)

FIG 35 TYPICAL 37 kV VERTICAL BLADE ISOLATING SWITCH

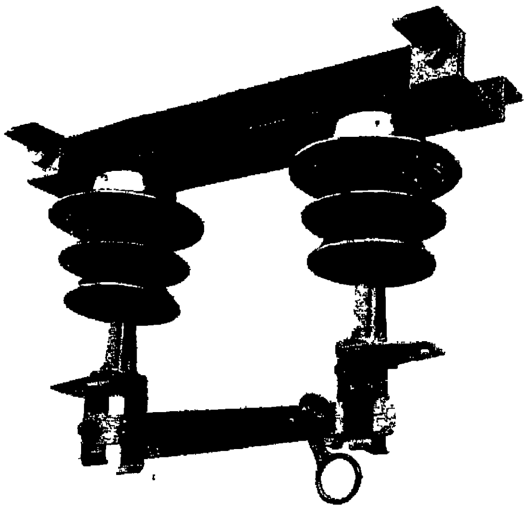
MISCELLANEOUS APPARATUS

Isolating Switches. Apart from obviously necessary changes in insulating means and in length of break, isolating switches for higher voltage work differ from those used on lower voltages mainly in mechanical arrangement In the following paragraphs are described the main variants employed, and their particular functions

Single-pole Switches. These are used with the closed blade either vertical or horizontal In the former case, the insulators may have their axes horizontal, or set at an angle of 45° as in Fig 35 Horizontal insulator posts, built of pin-type units, are to be deprecated over about 66 kV even indoors where the inclination of the rain sheds would be immaterial, because the great weight of the insulator post itself is liable to overstress

the porcelain nearest the point of support When the blade is horizontal, the insulators are always underslung, as indicated in Fig 36

On high-voltage work isolators must necessarily be



(B T -H)

FIG 36 TYPICAL 37 kV HORIZONTAL BLADE ISOLATING SWITCH

located high up, and it is important that proper means be provided for the reception of the operating hook stick The loop, if one is used, must be quite large, although a simple cross piece riveted to the blade is probably the easiest thing to catch hold of, either when closing or opening the switch

In the following table are given maximum overall

dimensions, which, if worked to, should ensure that any make of switch will go into the space allowed—

ISOLATOR DIMENSIONS

kV	Vertical blade				Horizontal blade, underslung			
	A	*B*	*C*	*D*	*A*	*B*	*C*	*D*
	ft in	ft in	ft in	ft in	ft in	ft in	ft in	ft in
11	2 11	2 3	9	1 5	2 5	1 9	9	1 5
22	3 3	2 4	10	1 6	2 9	1 11	10	1 6
37	4 5	2 7	1 –	1 11	3 4	2 2	1 –	1 9
50	5 2	2 8	1 2	3 –	4 5	2 4	1 2	3 –
88	5 2	3 9	1 5	4 –	5 –	3 9	1 5	4 –
110	—	—	—	—	5 6	4 6	1 5	4 6
132	—	—	—	—	6 11	5 10	1 5	5 –
154	—	—	—	—	7 6	6 1	1 5	6 –

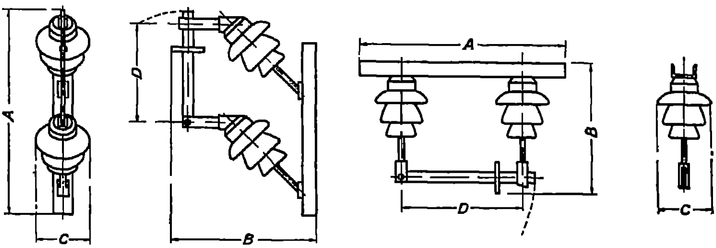


FIG 37 KEY TO SINGLE POLE ISOLATOR DIMENSIONS

Triple-pole Switches. The difficulty of manipulating a long hook stick places a distinct limitation on the use of single-pole isolators By far the greater number of installations use switches with all three poles coupled together and operated by mechanical means from a distance The mechanical drive may be by torsion rods, levers and tension rods, chain, wire rope, or any of the many means which readily come to mind The

choice of these calls for little comment The construction of the switch proper varies widely and the main types are described

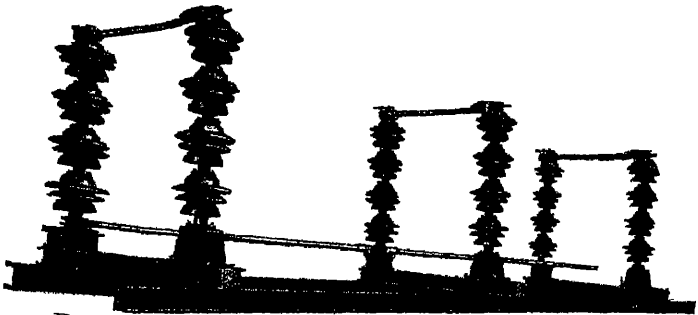


FIG 38 METROPOLITAN VICKERS SINGLE-BREAK ROTARY BLADE ISOLATING SWITCH

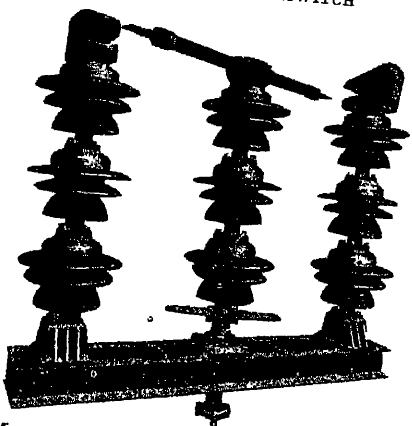


FIG 39 METROPOLITAN-VICKERS DOUBLE-BREAK ROTARY BLADE ISOLATING SWITCH

Rotary-blade Isolators may be built with two insulators and a single break per pole, as shown in Fig 38, or with three insulator posts, the central one of which

ISOLATOR DIMENSIONS

kV	Single break				Double break			
	A	*B*	*C*	*D*	*A*	*B*	*C*	*D*
	ft in	ft in	ft in	ft in	ft in	ft in	ft in	ft in
11	2 11	1 8	3 6	1 6	—	—	—	—
22	3 6	2 –	4 –	1 9	—	—	—	—
37	3 9	2 3	5 –	2 –	—	—	—	—
50	4 10	2 7	6 2	3 –	—	—	—	—
88	5 4	3 5	8 4	4 –	5 11	3 5	5 –	4 6
110	5 10	4 6	11 –	4 6	8 –	4 6	5 7	7 –
132	6 6	5 8	12 6	5 –	8 4	6 7	6 4	7 4
154	7 4	6 5	13 –	6 –	8 4	6 7	7 –	7 4

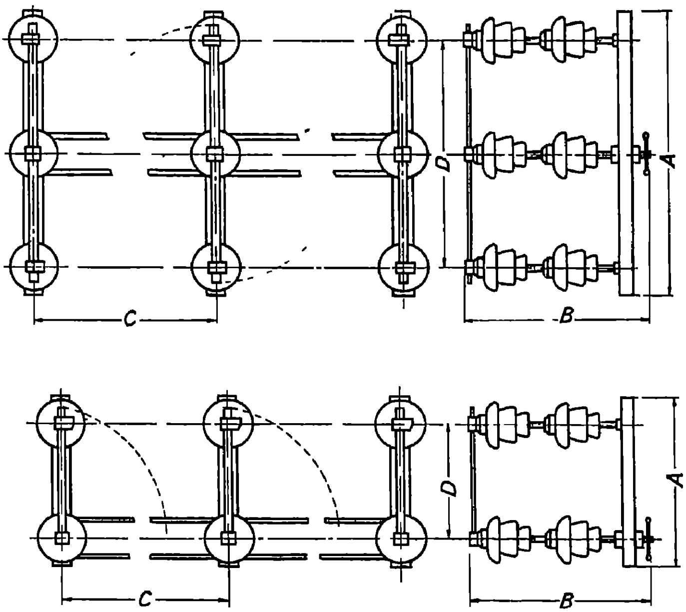


FIG 40 KEY TO ROTARY BLADE ISOLATOR DIMENSIONS

rotates, and carries the blade, giving a double b
This design is characterized by Fig 39 and is
preferred from a mechanical standpoint, althou
introduces an extra point for possible electrical tr
In employing switches of this class, it has

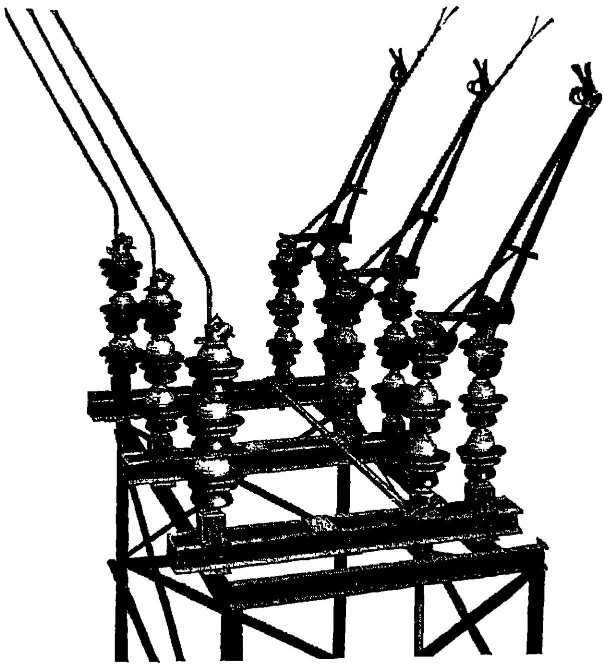


FIG 41 METROPOLITAN VICKERS 110 KV SWITCH

noted that in the double break form no risk at
because the blades approach each other wher
but if the single break pattern is used, care is nec
to ensure that the blade cannot be made alive
open, unless adequate blade-to-blade cleara
allowed Covering overall dimensions are tabula

Isolators with Vertical Blade movement provide wide scope for the mechanical designer, and there are numerous different patterns available Among those of

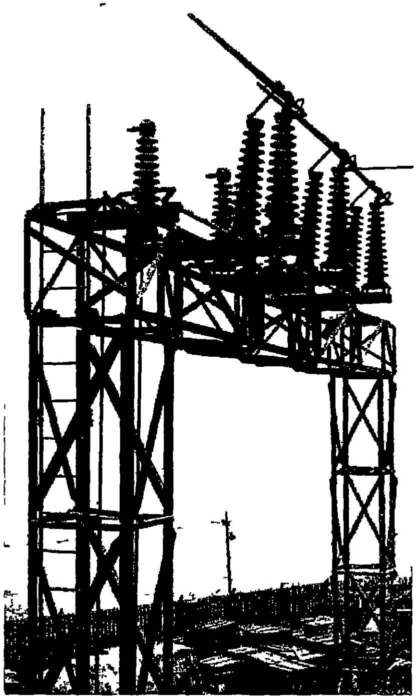


FIG 42 REYROLLE 132 KV VERTICAL-BREAK ISOLATING SWITCH

British make may be instanced that in Fig 41, which shows a switch fitted with horns, so as to render it suitable for breaking line charging or transformer magnetizing currents As a fact, such horn break devices have been known to break considerable powers,

but their action is so dependent upon wind strength and direction that they are usually regarded as quite

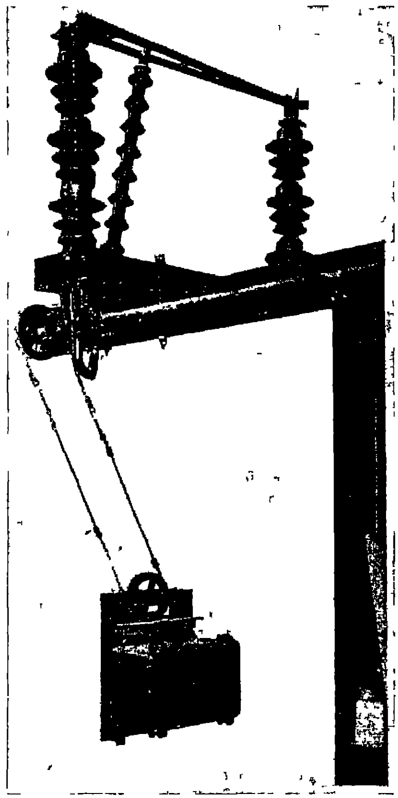


FIG 43 B T -H 110 kV VERTICAL-BREAK ISOLATING SWITCH

impossible means for routine switching work In the design shown, the intermediate insulator rotates, and moves a rack eccentrically mounted on the upper end

This, in turn, operates a pinion keyed to the hinge pin of the trussed blade

In another design (Fig 42) single-piece porcelain

ISOLATOR DIMENSIONS

kV	*A*		*B*		*C*		*D*	
	ft	in	ft	in	ft	in	ft	in
22	3	1	1	8	4	–	3	6
37	8	–	1	11	5	–	7	3
50	9	–	2	3	6	–	8	3
88	12	–	4	2	8	–	11	3
110	13	–	5	1	10	–	12	3
132	14	–	5	11	12	–	13	3
154	15	–	6	6	14	–	14	9

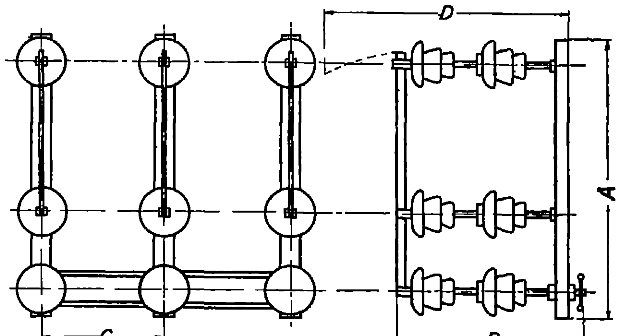


FIG 44 KEY TO VERTICAL-BREAK ISOLATOR DIMENSIONS

posts are employed even for outdoor work In this case, the intermediate insulator rocks about its base and moves the blade by a simple link clearly seen in the picture In this design, a torsion shaft is used for coupling the poles instead of the more usual double levers and links so disposed that one or other is always in tension

The design employed by the British Thomson-Houston Co. is shown in Fig 43 The mechanical arrangement is not unlike that used in the previous device, but in this case, movement is transmitted to the blade through an insulating link built up from moulded units, which screw one to the other.

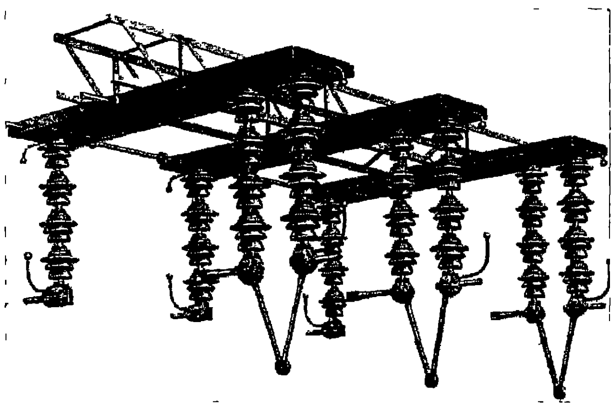


FIG 45 METROPOLITAN-VICKERS 132 kV CARRIAGE-TYPE ISOLATOR

Dimensions embracing any of the designs shown are listed in the table on page 609

The Carriage-type Isolator is a design evolved primarily to avoid need for extra clearances either above or beside the switch blades The most usual pattern follows that illustrated in Fig 45, from which it will be realized that the intermediate insulator is carried upon a wheeled truck bearing upon the base side channels An endless chain driven by a pinion and torsion shaft moves this truck to and fro, thus making or breaking contact

A variation of this idea is shown in Fig 46 In this

case, the contacting device is not carried directly by the moving insulator, but is connected thereto through a system of telescopic tubes enclosing a spring The major part of the insulator travel is employed in stretching or compressing the spring, which finally is released

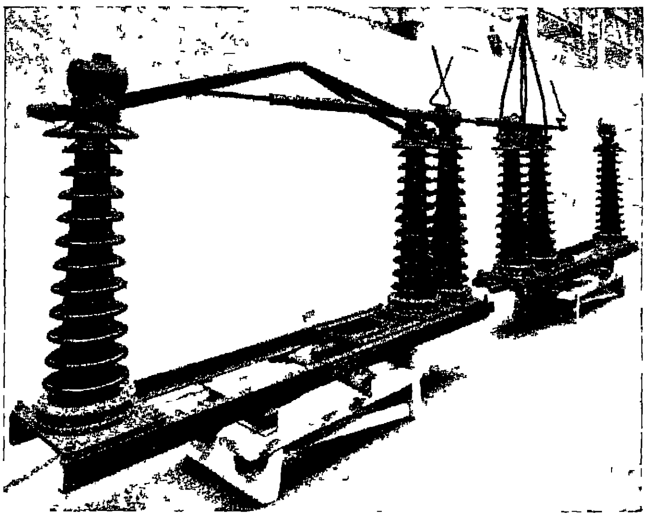


FIG 46 REYROLLE QUICK MAKE AND BREAK 132 kV CARRIAGE SWITCH

and imparts a quick breaking or making action to the contacts Such a device, fitted with the small horns shown, would be quite capable of interrupting moderate currents Toggled connecting links shunt the telescopic tubes and carry current to the moving contacts

The Suspension Type of Isolator, shown in Fig 47, is a very useful device on occasion, since it is supported by the conductors themselves, and no structural work is required Because it is not rigidly held, however,

it is somewhat awkward to handle, and there is also quite a risk that the supporting conductor may untwist slightly after some time in service, and thus move the blade out of its right plane For these reasons, the design is used only where alternatives are not possible

Earthing Blades may be added to practically any triple-pole isolating switch without appreciable increase in space occupied, the arrangement being used particularly on the line side of feeder isolators, so as to

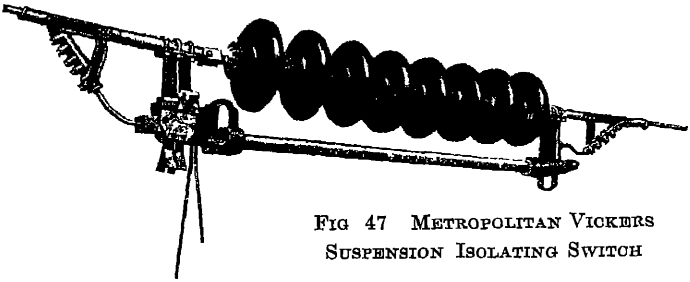


FIG 47 METROPOLITAN VICKERS SUSPENSION ISOLATING SWITCH

make quite certain of the safety of men working on the overhead lines

Weather Shrouding around the contacts has been the subject of many ingenious patents and designs While it is probably just as well to protect the actual contact surfaces of an open switch, the design has yet to be produced which will prevent a closed switch from freezing up If the contacts proper are guarded, ice is sure to form from guard to blade, which is just as serious

The most practical arrangements are those such as are fitted to the switch shown in Fig 41, in which the switch arm is hinged at its extremity This acts as a toggle in opening, and exerts a sharp wrench on the contact faces, sufficient to break away all ice in that vicinity

Potential Transformers. As the working voltage increases potential transformers get more awkward to build, and, consequently, more costly Up to 50 kV, or perhaps, 60 kV, they may be regarded as a practical proposition, to be installed with the usual equipment of protective resistances, fuses, and isolating switch Beyond these limits, every effort must be made to avoid their use

Means are available whereby potential transformers on the low side of a power transformer can be compensated so as to show correctly the high side potential, even when the main transformer has tap-changing gear

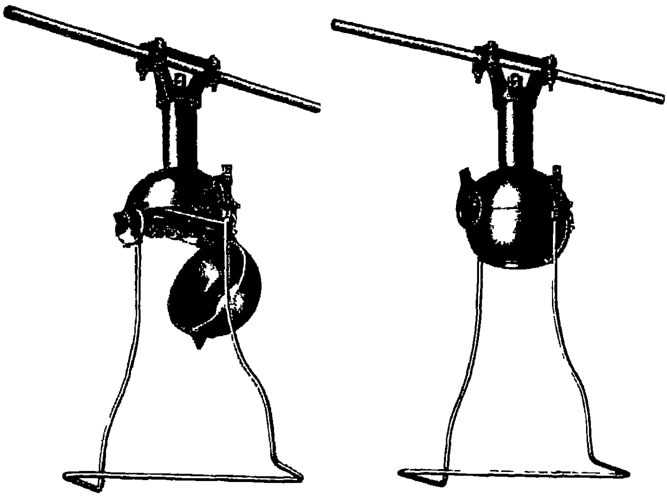
For many purposes, such as the operation of neon tube synchroscopes, ground indicators, etc , a tapping is made across the earth end unit of a string of suspension insulators, the potential bearing a relation to the voltage across the whole string which is near enough for such services

The most recent device, which has already been applied successfully for relay and wattmeter operation, and which is quite accurate in all conditions, employs a potential transformer connected between the earth band and the first foil layer of a condenser bushing, the potential between which is commonly of the order of 5000/7000 volts A phantom earth band has been inserted in oil-filled bushings to permit this method to be used where condenser type bushings are not available

Current Transformers. It has already been indicated that ring-type transformers, threaded over circuit bushing insulators, are the most economical means of making current measurement These are necessarily excited by a single primary turn and, consequently, at low current values the ratio is not accurate In most cases the difficulty can be overcome by using relays and instruments designed to absorb small energy

and by calibrating them with their transformer The practical limit of primary current to-day is about 15 amp normal full load on 37 kV, to 60 amp on 132 kV systems

Wound primary current transformers can be made for any service voltage, and, although expensive, their



Open for Inspection Closed

FIG 48 WESTINGHOUSE ELECTROSTATIC GLOW TYPE POTENTIAL INDICATOR

design presents an easier insulation problem than does that of a potential transformer It is desirable to shunt the high-tension terminals with a non-inductive resistance, to provide a by-pass for possible high-frequency or steep-fronted waves

Potential Indicators. In some countries it is compulsory to fit on all conductors in a station, devices which will indicate when they are under pressure The usual Continental instrument is virtually a ruggedly

built leaf electroscope hung on the conductors. Indoors such an instrument is quite practicable, but if it is located at any height, particularly out of doors it is quite hard to see the vane position.

As an alternative arrangement electro-static voltmeters have been used. The high cost, coupled with the fact that they must necessarily be under cover, imposes a limit in connecting them directly to the high-voltage conductors, so that in the majority of cases the voltmeter has actually been connected to the first intermediate metal fitting of a convenient multi-unit post insulator. Even when this is done the arrangement involves running extra leads at high potential from the switch yard to some convenient building, and as these leads themselves have an appreciable capacity compared with the capacity of the voltmeters, very great care is necessary in disposing them.

The best device yet evolved is that shown in Fig. 48, which comprises a neon filled tube connected between the conductor and a bent wire, counterpoise earth. The tube is deeply recessed in a large insulating case with a window in the under side, the whole device being clamped on to the conductor in any convenient position. The glow can be seen from a distance even in bright sunlight. The bent wire frame is supported from the insulating case so that this, with the conductor itself, constitutes a small condenser, the charging current for which, when the line is energized, serves to cause the neon to glow.

Grounding Devices. When discussing isolating switches passing reference was made to the use of additional grounding blades, the purpose of which is to connect to earth the dead feeder line so as to make quite sure that no danger can occur to men working on the line. It is hardly possible to arrange similar devices in respect of every conductor throughout a

station, but at the same time it is very necessary to safeguard the workers, and it should be a standing instruction that no man commences to work on any apparatus until all associated conductors are definitely earthed in his presence Probably the most convenient way of ensuring this is by the use of a length of flexible conductor terminating in spring clips The most popular is that known as the "Johnson" type, and is not unlike an enlarged version of the ordinary stationers' bulldog clip with flared jaws In use one end of the flexible conductor is attached to any convenient grounded point, and the earthing clip is then raised on the end of a wooden rod and hooked over the conductor which has to be earthed The rod is provided with a screwed end so that it can be removed as soon as the earthing clip is in place It may be noted that for this purpose the conductors should be continuous wires Chains are liable to develop insulating coatings over the individual links, resulting in very high overall resistance

SECTION XI

GENERATING VOLTAGE SWITCHGEAR

BY

C C GARRARD, PH D., M I E E,
A AM I E E

SECTION XI

GENERATING VOLTAGE SWITCHGEAR

(APPARATUS AND LAYOUTS AND SWITCH-HOUSE DESIGN)

INTRODUCTION

BY far the largest proportion of electric power is generated upon the three-phase system, and this is likely to be the case for many years to come Further, of three-phase alternators, the large majority have been for voltages in the neighbourhood of 6600 volts For small distances transmitted (say about 5 or 6 miles) this voltage has been sufficiently high to secure economical transmission and, consequently, many supply authorities, working on the three-phase system, have distributed to their substations at the generator pressure without stepping up to a higher voltage In the larger cities, and in the case of power companies supplying large areas, 6600 volts have been found to be insufficient, and voltages of 22,000 and 33,000 volts have become common In such cases step-up transformers are used to increase the generator voltage to the values indicated When it came later to transmitting large blocks of power and interconnecting networks far removed from each other, then even 33,000 volts were found insufficient and various higher voltages up to 380,000 have been used, depending on the circumstances of the case

LIMITS OF GENERATOR VOLTAGE

As an electric generator is of necessity an air-cooled rotating machine, the voltage it can be run at is limited

to a relatively low value An attempt has been made to construct a three-phase generator to work at 33,000 volts This design, however, is not likely to be imitated to any large extent For generators of moderate size the voltage of 6600 has been found to be very convenient, but for the largest machines 11,000 volts are better, and this figure generally nowadays is adopted One reason for this is the limitation fixed by the value of the current in amperes to be dealt with It is found, at 50 periods, very expensive and inconvenient to construct switchgear and connections for alternating currents above about 3000 amp With currents greater than this the size of the conductors is so large that, owing to skin effect, the distribution across the cross-section is not uniform, thus the material is not used economically, and difficulty is experienced in avoiding eddy currents and getting the gear to run cool Now, 3000 amp at 6600 volts correspond to about 34,000 kVA, and single-unit machines of this size and larger are to-day common In these very large machines, therefore, a more convenient voltage is 11,000, as this reduces the necessary size of conductors by 40 per cent, and is at the same time a voltage which does not put any undue demand upon the resources of present-day insulation and machine construction Consequently, 11 000 volts is now the usual pressure adopted for the large generators now used

GENERATOR VOLTAGE SWITCHING

Generator voltage switching can be defined as switching on a busbar fed direct by the electric generators without the interposition of transformers, and such as is the case if the system be only a 6600 or 11,000 volts one

Generating voltage switching can, however, be used if the system is a 33,000 volts (or higher) one The

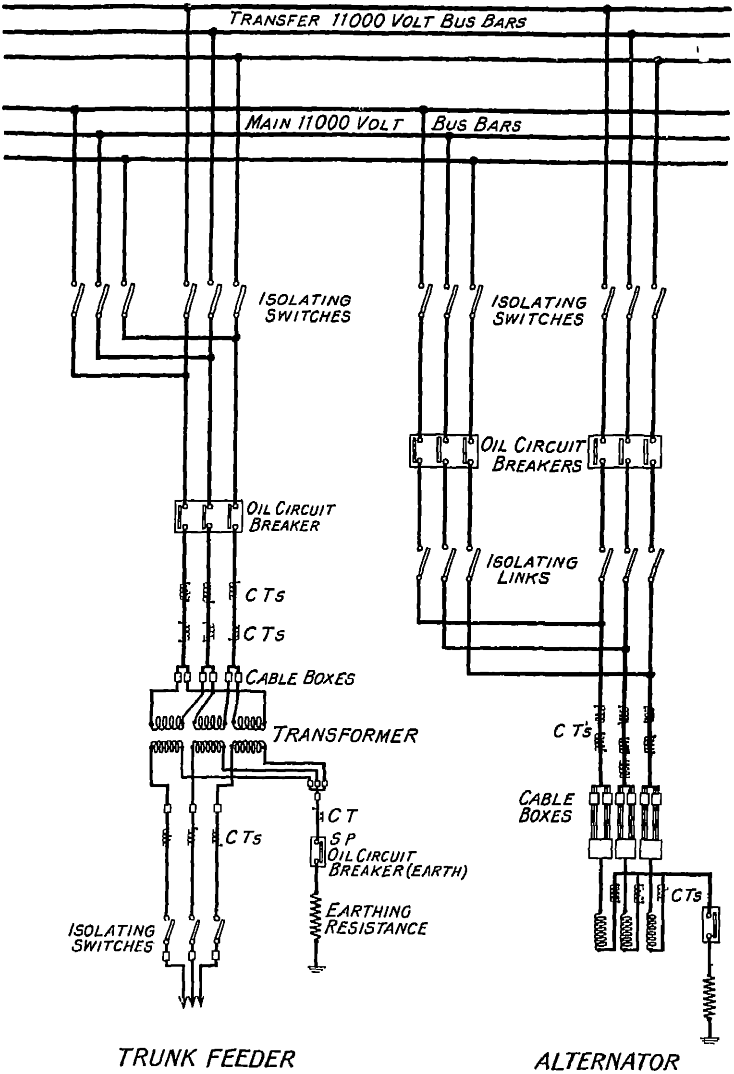


FIG. 1. MAIN SCHEMATIC DIAGRAM FOR HAMS HALL POWER STATION, BIRMINGHAM CORPORATION

main busbars are then at generating voltage and the step-up transformers are fed from the bus through oil circuit breakers Oil circuit breakers can also be used on the higher voltage side of the step-up transformers which, of course, makes an expensive arrangement The Hams Hall Power House of the Birmingham Corporation is designed on this principle, but no oil switch is used on the higher voltage side of the step-up transformer (see Fig 1) The more usual arrangement nowadays for very big stations is, however, to dispense with generating voltage busbars altogether In this case each generator has its own bank of step-up transformers, and this, together with the generator associated therewith, can be regarded as one unit (see Fig 2)* This is the cheaper arrangement, and experience shows it is altogether satisfactory The fears that such a scheme may cause resonance conditions to be set up are groundless Both in America and on the Continent the trend of opinion is decidedly against generating voltage switching in new really large power houses In many cases, however, local conditions require generating voltage switching, and in the following pages the principles underlying such switchgear are dealt with

BREAKING CAPACITY OF GENERATOR CIRCUIT BREAKERS

If an alternating current generator be suddenly short-circuited a very large initial rush of current occurs during the first small fraction of a second , this is followed by a rapid diminution of the current flowing, and in a second or two the short-circuit current will only amount to about two or three times the full-load rated current of the machine This sequence of events is illustrated in Fig 3, which gives the results of tests

* The cross connecting cables shown at *X* (Fig 2), are only intended to be used in case of emergency

made on a machine at the Carville station of the Newcastle Electric Supply Company Owing also to a phenomenon known as the doubling effect, the initial instantaneous short-circuit current is not the same in all three phases, whereas the sustained short-circuit

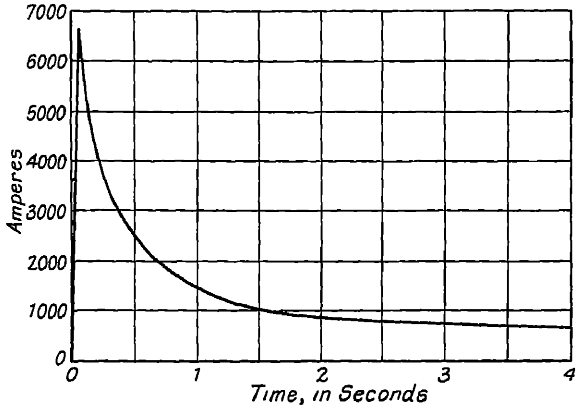


FIG 3 FLOW OF CURRENT IN SUDDEN SHORT CIRCUIT OF 4000 KW 5800 VOLTS THREE-PHASE TURBO-ALTERNATOR

(Full load current, 400 amp)

current (flowing after 2 or 3 seconds) is equal in all phases provided, of course, that the resistance in the path of the current is equal in all phases

Now, the current which a generator circuit breaker is called upon to rupture is, generally, not the initial, almost instantaneous, current, as no make of oil circuit breaker (the type almost universally used) operates quickly enough to do this Moreover, it is not desirable, as will be seen later, that the generator short circuit should be ruptured as quickly as this In the case of some machines, such as rotary convertors, the opposite of this is aimed at by the use of high-speed breakers This is to prevent commutators flashing which, of

course, does not arise with an alternator The fact that an oil circuit breaker takes sufficient time to function to allow the initial short-circuit condition to be over before operation takes place is beneficial, as the duty imposed upon the breaker is thereby lessened as the current actually broken is less It is found that, provided no intentional time-delay mechanism is used, the current actually broken when a dead short-circuit on an alternating current three-phase generator is interrupted by an oil circuit breaker, is about six times full load current Of course, this value varies with the design of the machine, but six times is a good average figure, and this figure is generally adopted for determining the required rupturing capacity of a generator oil circuit breaker Thus, if there be two 10,000 kW generators feeding on to a busbar (with no other synchronous plant in the system), then the required breaking capacity of each circuit breaker on the busbars would be six times 20,000, that is to say, 120,000 kVA This gives a very easy rule for determining the necessary breaking, or rupturing, capacity of an oil circuit breaker in a generating station It is true any synchronous plant in the substations, by feeding back, will increase the possible short-circuit Generally speaking, owing to the reactance of interposed plant, this addition is but small and will be covered if a reasonable margin (say 25 per cent) be allowed in the circuit-breaker rating It must be added that all the breakers connected to the same busbar should be equal to each other in breaking capacity, no matter what circuit they control, as it is obvious they may be equally stressed by short-circuits To lessen the cost of this arrangement, feeders are sometimes provided with smaller breakers but in this case they should be connected to an auxiliary busbar which should be itself protected by a larger group circuit breaker This is

quite a sound scheme and is often adopted in modern working

TYPES OF SWITCHGEAR

If there be one branch of electrical engineering in which Great Britain undoubtedly takes the lead, it is in the design of alternating current switchgear for voltages of 3300 to 11,000 volts In fact, there is quite a bewildering choice of types, a state of affairs that exists among the manufacturers of no other country Most of the underlying principles of modern switchgear were first enunciated in this country The cellular construction of Ferranti, compound-filled switchgear of Reyrolle, truck switchboards, all these originated here On the other hand, the credit for the development of the isolated phase system belongs to the United States of America The various types of switchgear now being considered may be enumerated as follows—

1 CUBICLE TYPE Simple and subdivided cells, interlocked type, truck gear

2 CELLULAR TYPE Fireproof (concrete or brick), cellular and compound-filled combined

3 METAL-CLAD TYPE Compound and oil-filled types

4 ISOLATED PHASE TYPE

CUBICLE TYPE SWITCHGEAR

Cubicle switchgear is the simplest type which is permissible for use in this country for 3300 volts and above On the Continent, switchgear of the open type is often used for these voltages The clearances, it is true, are often large, but the possibility of the unhindered spread of fire, added to the undoubted greater danger to life would not be tolerated here Moreover,

the Home Office Regulations do not permit of its use Steel cubicle switchgear is suitable for voltages up to 11,000, and with oil circuit breakers, up to about 150 000 kVA breaking capacity

These limits have been exceeded occasionally, but it is better, in such cases, to use a more highly-developed type

The simplest form cubicle switchgear can take is the enclosure of all live parts, panel for panel, within steel-plate cells or cubicles, the indicating instruments, oil circuit breaker handles, etc being on the front If space be restricted the doors for giving access to the interior may be on the front also, generally so constructed that they can be opened without disturbing the oil switch Such a cubicle switchboard is illustrated in Fig 4

All switchboards of whatever type must be provided with means of isolating the oil circuit breakers from the busbars After opening these isolating links the oil circuit breakers can, generally speaking, be handled and cleaned, etc If instruments and the like are mounted on the upper front plates which cover the busbar section of the cubicle, it is clear that the back terminals and the connections to the instruments, cannot, unless some appropriate construction be adopted, be got at safely while the busbars are alive

Fig 5 shows a method for dealing with this difficulty It will be seen that the instruments are mounted on a hinged plate On swinging this plate open the back terminals can be inspected in perfect safety, as a second protecting door is arranged inside the cubicle behind the front one, and this effectively screens the high-tension connections This second door or screen is preferably made of expanded metal, enabling the inside gear to be inspected It can be itself hinged and secured with a padlock

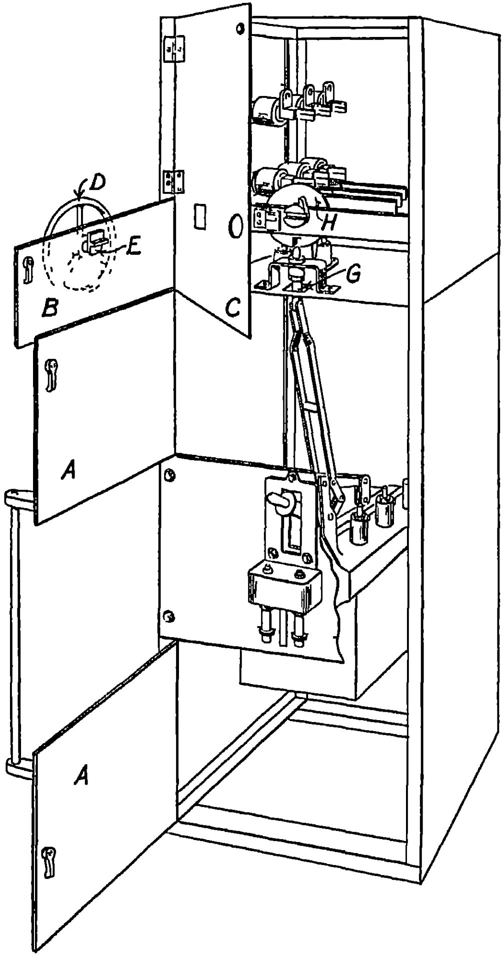


FIG 4 EXAMPLE OF CUBICLE SWITCHGEAR

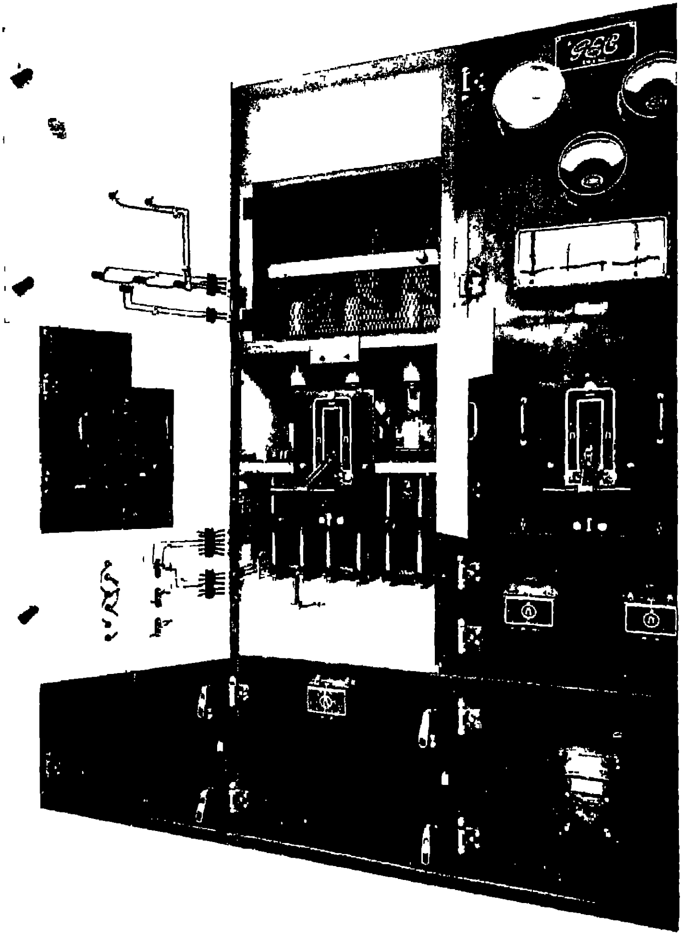


FIG 5 FRONT ACCESS STEEL PLATE CUBICLE SWITCHBOARD, SHOWING INTERNAL EXPANDED METAL DOOR COVERING ISOLATING LINKS

A far better general arrangement of a cubicle switchboard is to have back rather than front access The various subdivisions of the cubicle have their respective back doors accessible from a passage at the back of the switchboard The arrangement of hinged front plate, carrying the upper instruments (see Fig 5), is also desirable with back-access cubicles

All cubicles have to be subdivided in order that they may be safe and comply with the Home Office Regulations

If the isolating links are operated by means of a pull-rod after opening a door, which is an excellent and simple arrangement, it is necessary that the link compartment be separated both from the busbar compartment and from that containing the oil circuit breaker The Home Office Regulations require, moreover, that the door of the link compartment shall be shut before any work be done in the oil circuit breaker compartment This is because the link compartment contains parts which are connected to the busbar and which may be alive, even when the links are in the off position

It is very desirable, however that access should not be possible to the oil-breaker compartment until the link compartment has been previously opened thus drawing the attention of the operator to the possibility of closed links

INTERLOCKING ON CUBICLE SWITCHBOARDS

Many ingenious devices are used to secure various degrees of interlock on cubicle switchboards For example a mechanical connection may be arranged between the oil breaker and the isolators, so that these latter can only be opened when the former is in the "off" position If the isolating links are pull-rod operated (i e by means of an insulated long arm from the outside), this form of interlock is not necessary

The greatest possible simplicity in interlocking arrangements is very desirable This can be attained in cubicle interlocking as follows—

SIMPLE CUBICLE INTERLOCK

The door covering the oil-breaker compartment should be provided with a catch so arranged that this door cannot be opened until that covering the isolating

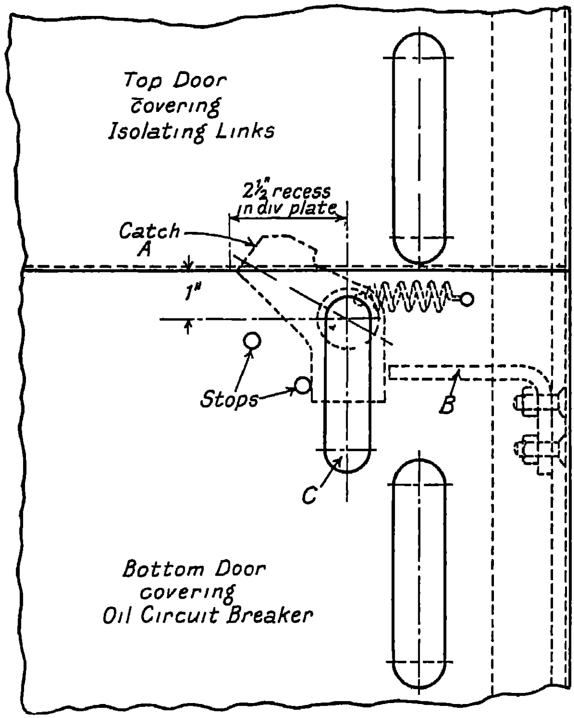


FIG 6 METHOD OF INTERLOCKING OIL CIRCUIT-BREAKER COMPARTMENT DOOR WITH THAT COVERING ISOLATING LINK CELL

links has been previously opened Thus, the attention of the operator is drawn to the fact that the breaker may be alive Otherwise, he might, without thinking expose and handle the live parts It is also possible, by a very simple arrangement, to prevent the circuit-breaker door being opened until the breaker itself has been opened , thus, danger of breaking circuit on the links is prevented It should be possible, however, to reclose the breaker while its door is open, the links having previously been opened This is necessary for adjustment purposes The isolating links having been opened it must be possible to reclose the isolating link compartment door, leaving, however, that of the circuit-breaker compartment open On reclosing the latter, however, it must only be possible to open it again by going through the sequence of first opening the door covering the isolators

These arrangements, which give a high degree of safety combined with maximum simplicity, are illustrated in part in Fig 6 It will be seen that the hinged catch *A*, both doors being shut, prevents the lower door, on which the catch is fixed, being opened until the upper one has been first opened The catch *A* can be rotated out of engagement with the upper door by means of the handle *C* This is, however, only possible when both doors are open, as in the closed position the abutment *B*, which is fixed to the rigid cubicle frame, prevents rotation of catch *A* When both doors are open then *C* is turned and the upper door can be reshut, leaving the bottom one open

CUBICLES WITH EXTERIOR-OPERATED ISOLATING LINKS

In this type of cubicle (compare Fig 4) the isolators are operated by an external handle or handwheel The object of its use is to allow less skilled attendants,

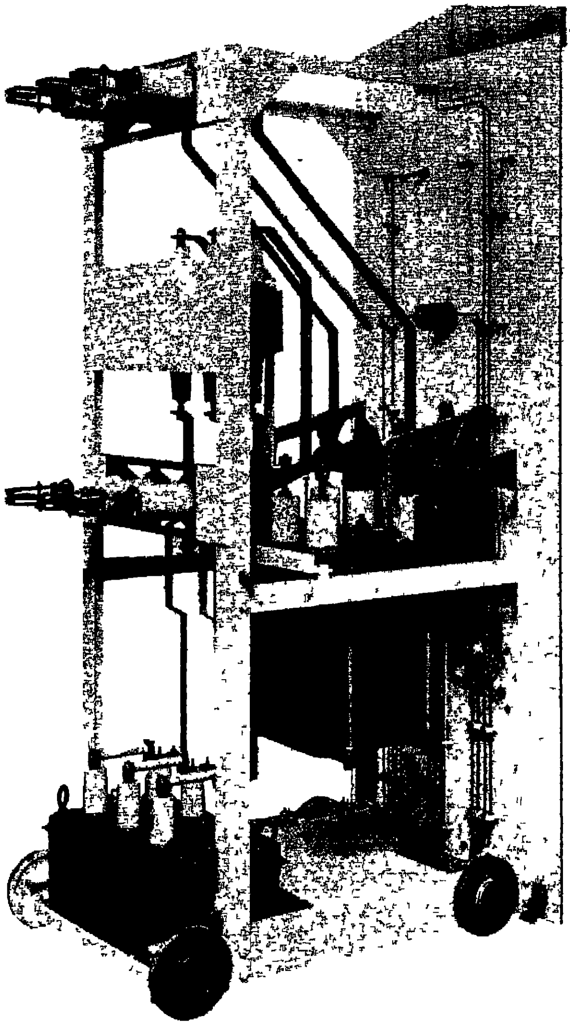


FIG 7 TRUCK TYPE PANEL
Truck shown withdrawn from switchboard

as access to live metal, provided everything is in proper working order, is absolutely prevented Naturally, a complete system of interlocking, which should be mechanical and not electrical, is necessary so that the sequence of events in obtaining access to the circuit breaker must be—

(*a*) open circuit breaker ,
(*b*) open links ,
(*c*) open circuit breaker compartment door ,

with the reverse of this after the inspection As often arranged the scheme has the disadvantage that it is not possible to *see* that the links are open This can be obviated by having a glass panel in the link door which, however to a certain extent, detracts from the safety against fire of the board

TRUCK SWITCHBOARDS

In this type of board all the apparatus forming a panel, with the exception, of course, of the busbars and the isolating contacts associated therewith, are mounted on a wheeled carriage or truck The whole can then be wheeled away for cleaning and inspection with a high degree of safety The compartment from which a truck has been removed must be completely enclosed with metal and must be provided with an automatically closing device or shutter to cover up the contacts connected to the busbars with which the projecting jaws or plugs on the truck make connection on wheeling the same in

Naturally, also, it must not be possible to pull a truck out until the circuit breaker has been opened, nor to push in the truck with the breaker closed A very simple mechanical device ensures these conditions Fig 7 illustrates such a wheeled truck as described above, with a framework made entirely of steel

(English Electric Co)

FIG 8 HIGH TENSION OIL SWITCH, BLACKBURN (EAST) POWER STATION, SHOWING SEPARATION OF PHASES

CELLULAR TYPE SWITCHBOARDS

The term cellular type is generally applied to those switchboards built up of brick or stone in the form of cells, in which the various pieces of apparatus are placed more or less isolated (in the mechanical sense) from each other

The greater this relative isolation the safer is the arrangement Important boards are generally arranged with phase separation, that is to say, each phase is separated by a fireproof wall 3 or 4 inches, or more, thick Fig 8 illustrates how this is done in the case of an oil circuit breaker This phase separation is particularly desirable in the space just above an oil circuit breaker The reason of this is the liability of arcing across between the bare terminals of the breaker at the instant of operation under heavy short-circuit This is sometimes attributed to the fumes or gases emitted from the oil tank at that moment It is doubtful, however, if this is the real cause of this phenomenon One possible explanation is that it is a kind of electrical water-hammer effect causing a piling up of potential at the breaker due to the sudden rupture of the circuit Whatever may be the cause, bare terminals on a large important cubicle-type circuit breaker should never be allowed The insulation placed on the conductors leading to the circuit breaker need not be high, nothing approaching the value which would be necessary to insulate the conductors from earth Several layers of insulating tape, on a 6600 volts circuit, are sufficient This should be done, at least in the cell immediately above the oil circuit breaker, in all important installations In fact, the complete insulation of the conductors throughout the entire board is an excellent arrangement It, of course, adds considerably to the cost, and is, therefore, often

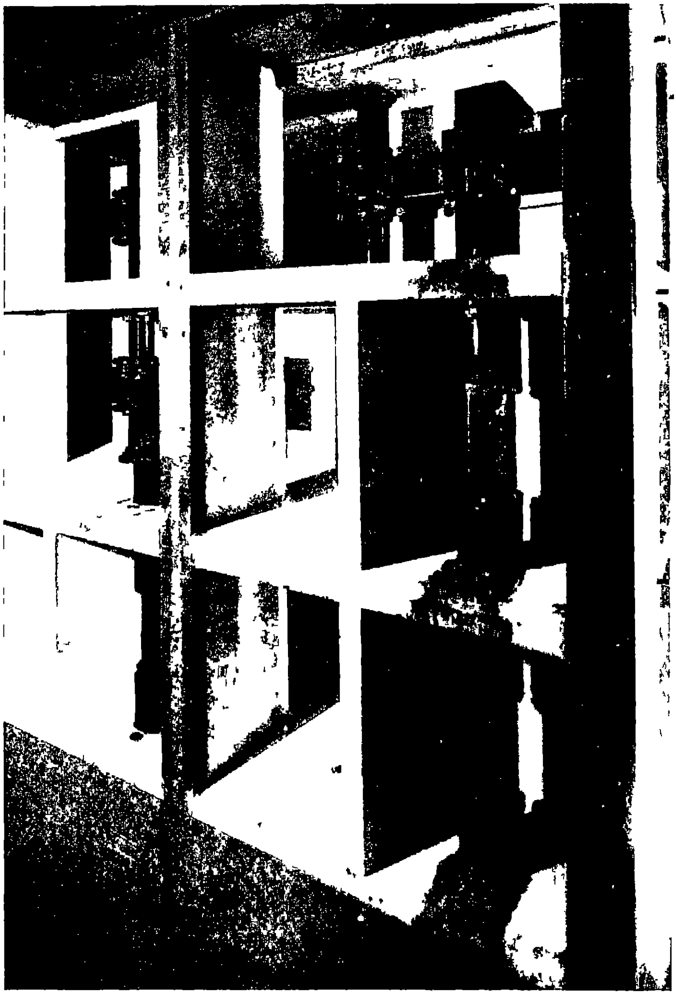
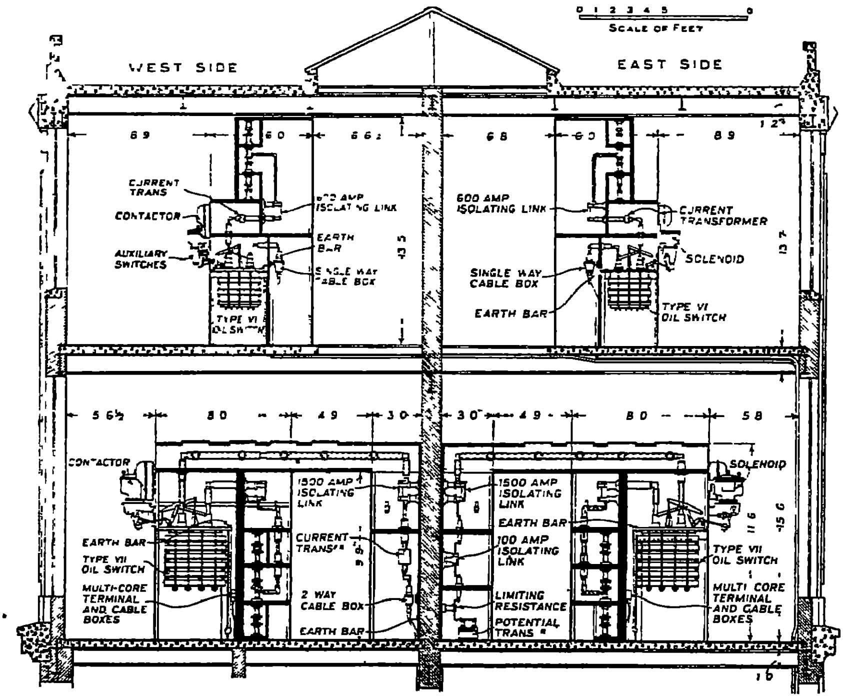


FIG. 9 GENERAL VIEW OF MICA-INSULATED BUSBARS TAKEN IN NECHELLS POWER STATION, BIRMINGHAM



(*General Electric Co*, *Ltd*)

FIG 10 CROSS SECTION OF CUBICLE SWITCHGEAR AT PRINCE'S POWER HOUSE, NECHELLS, BIRMINGHAM CORPORATION

omitted The cubicle type of switchgear of the Prince's Generating Station of the Birmingham Corporation (see Fig 9), is a good example of this system Every conductor throughout the board, with the exception of the isolating links, is covered with a layer of cured-on micanite At joints in the connections and busbars this secondary insulation takes the form of bakelite boxes fitting over the clamps and bolts The micanite insulation itself is sufficient to withstand a specified test voltage of 20,000 volts, but is not relied upon for the primary insulation, which takes the form of bakelized paper busbar supports and bushes

SINGLE-FLOOR CUBICLE BOARDS

Large cubicle boards are often arranged to occupy two or more floors It sometimes happens that a good deal of space is wasted with cubicle boards due to the lack of a little ingenuity, so that cubicle boards have acquired the reputation of requiring a very much larger space as compared with metal-clad gear than is actually the case It will be seen from Fig 10 which is a large and important installation, the lower circuit breakers having a rupturing capacity of 800,000 kVA, is a single-floor arrangement

Figs 12 and 13 illustrate other single-floor arrangements suitable for somewhat smaller breaker capacities for single and double busbars respectively It will be seen that the whole of the gear is contained in each case in a single structure and occupies very little more floor space than does the corresponding metal-clad type, the head-room is, it is true, larger

COMBINED CUBICLE AND COMPOUND-FILLED SWITCHGEAR

A convenient method of keeping down the head-room of cubicle-type boards is to enclose the busbars

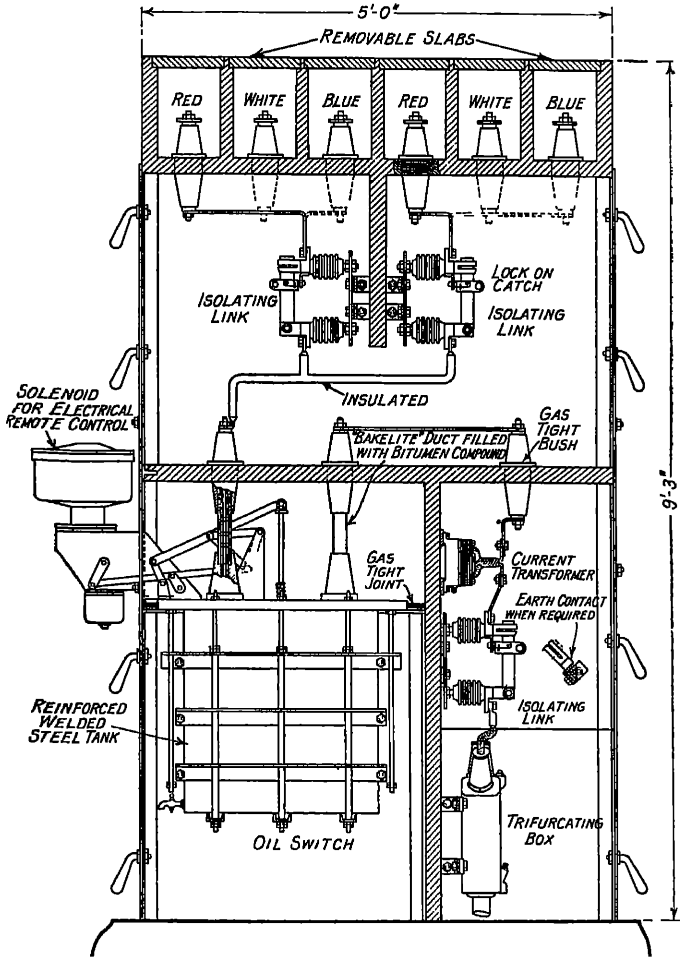


FIG 13 ARRANGEMENT OF CUBICLE FOR 6600 VOLT DUPLICATE BUSBARS

Single floor arrangement

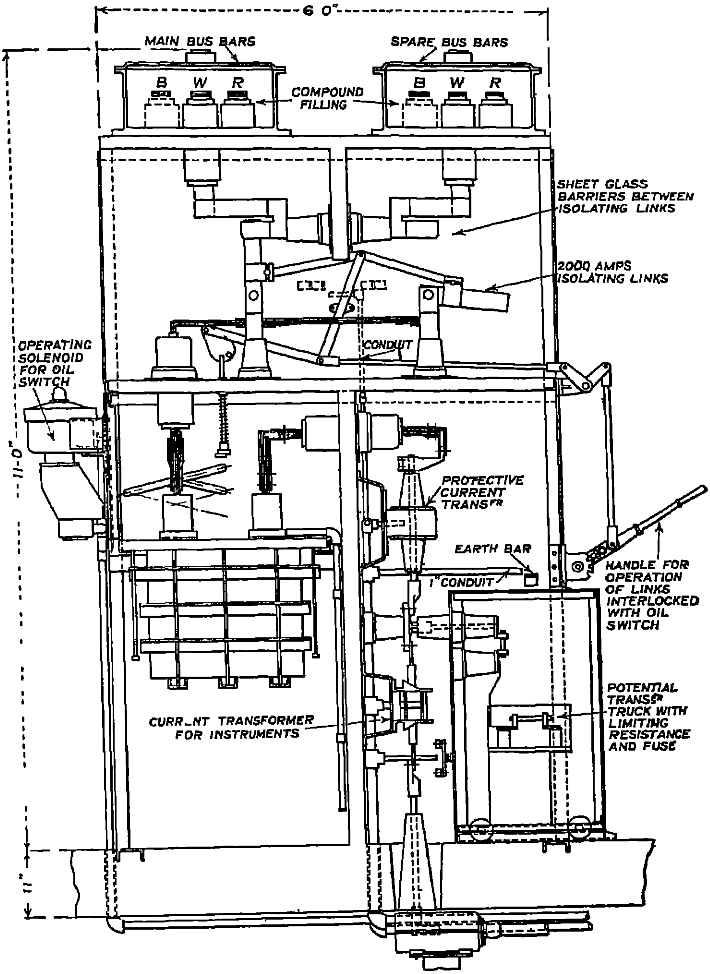
in compound-filled chambers This is shown in Fig 14, the circuit breakers being 250,000 kVA breaking capacity This illustration also shows a convenient method of housing the potential transformer This is often a troublesome business, and sometimes complete panels are allocated to this purpose By mounting the potential transformer with its fuses and protective resistances in a small wheeled truck, a very considerable saving in space results

It will be seen in Fig 14 that the links are operated by levers from the outside, necessitating, of course a mechanical interlock with the oil circuit breaker It is better, however, to dispense with this and have the links pull-rod operated, and in this case no such interlock is required Such boards are cleaned by skilled attendants, and the simplification resulting from the abolition of this kind of interlock is an advantage Indeed, it is this question of simplicity that causes many engineers to prefer the cubicle type of gear to the metal-clad Everything is more easily got at than in this latter type, but cubicles require more cleaning of insulators, etc It goes without saying that a properly constructed cubicle switchboard should be entirely vermin-proof, and no trouble due to rats and mice should occur

This source of trouble is also additionally guarded against by the conductors themselves being covered with insulation as described above (Fig 9)

METAL-CLAD GEAR

In this class of switchgear all conductors are enclosed within metallic covers or boxes being insulated therefrom generally by compound, although in recent years oil has also been used This construction naturally reduces dimensions somewhat, but as the main determining factor in the size of a switchboard is the oil



(*General Electric Co, Ltd*)

FIG 14 CUBICLE SWITCHBOARD WITH COMPOUND FILLED BUSBARS

circuit-breaker tank, the floor space occupied is not very different for equal-sized circuit-breaker tanks, the main

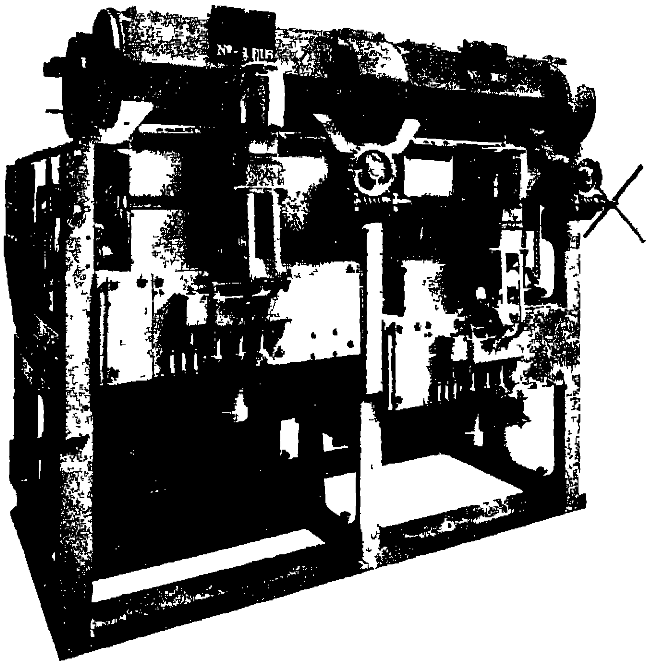


FIG 15 METAL-CLAD OIL CIRCUIT BREAKERS, 11,000 VOLTS, THREE-PHASE, 50 CYCLES

Front view Drop-down isolation

saving being the elimination of the barriers between phases and between panels

Metal-clad gear is practically always of the truck or drop-down type, the oil circuit breaker being isolated by

running it out of contact with the busbars on a wheeled truck or lowering it by a screw or worm-wheel arrangement for the same purpose The former method, while it has been used for large capacity gear, is most suitable for the smaller types For large circuit breakers the drop-down principle would seem to be the most advantageous, there can be no doubt that it results in a saving in floor space compared with the racking-out variety Fig 15 illustrates an example of the drop-down type The busbars are shown projecting out of the busbar chamber ready for bolting to an adjacent section

DUPLICATE BUSBARS WITH METAL-CLAD GEAR

The method which has been used mostly in the past for changing over a metal-clad circuit breaker from one set of busbars to the other, is to withdraw the breaker on its runway, remove the plug contacts, say, from their upper contacts to the lower set (or vice versa), and then rack the circuit breaker in again This process takes some time Various other methods have been used, as follows—

1 Arranging one half of the contacts of the circuit breaker so that they can rotate, the same being suitably shaped so that in one position they make contact with one busbar, and when turned 180 degrees with the other Fig 16 is an example of this method

2 Incorporating a change-over oil-immersed switch in the gear and interlocking it with the circuit breaker

3 Making the circuit breaker a double one, viz two breakers in the one tank

4 Arranging the circuit breaker to drop down out of contact with the one bus, then moving it bodily until it is underneath the other bus and then raising it into contact

5 Use of two separate and distinct circuit breakers

per circuit, interlocked with each other so that only one can remain closed at a time

Of the above methods, No 5 is the best, but is expensive It is, however, in fact, the only safe method

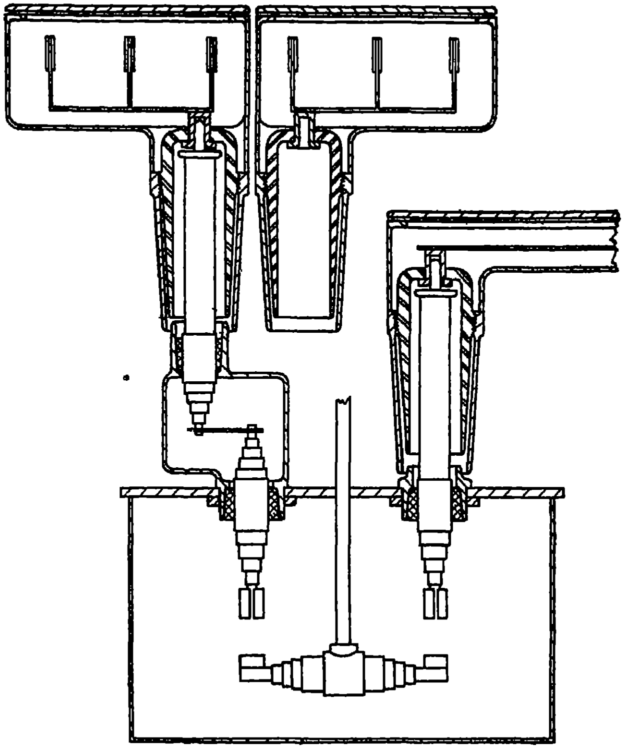


FIG 16 BUSBAR SELECTION BY ROTATING CONTACT METAL CLAD GEAR

of changing circuits over from one bus to the other without breaking circuit under load

Nos (1) and (4) are about equally convenient, but No (4) requires naturally the larger structure

No (3) has the disadvantage that both busbars are liable to be involved in any trouble with a circuit breaker, and the cleaning of a dead busbar is somewhat dangerous

No (2) is a fairly good scheme, but is nearly as expensive as No (5) and, moreover, it cannot be used with safety to change-over circuits under load. No. (5) system, therefore might as well be used especially as it is, of course, much better technically than No (2) It must be remembered that the two sets of busbars should never be coupled, if only momentarily, except through a circuit breaker, they must not be coupled through the change-over switch in method (2)

OIL-FILLED METAL-CLAD GEAR

It is a disadvantage of metal-clad gear that the various enclosed pieces of apparatus, e g current transformers, are, compared with cubicle gear, difficult to get at as may be necessary for recalibration and the like, due to their being encased in compound Moreover, due to the heat insulating properties of compound, the current density of copper connections has to be reduced. To get over these objections oil has been used instead of compound, the busbars, etc, being arranged within oil-tight enclosures This considerably increases the volume of oil required and the greater fire risk must not be overlooked

Oil, unfortunately, is necessary in the case of switches and transformers, but to use it where it is not absolutely essential would seem to be, on balance, of doubtful advantage

OUTDOOR METAL-CLAD SWITCHGEAR

A recent development of metal-clad switchgear is the outdoor type which has been used in America (see *Electrical World*, 28th July, 1928, page 153, describing

the installation at Wheaton Illinois) A cross-section of this installation is shown in Fig 17 It will be seen that drop-down isolation is used, the oil circuit breakers, which are rated at 1,000,000 kVA breaking capacity, being lowered for inspection or renewal by a motor-operated elevator Thus, separate motor operation for lowering each circuit breaker is obviated The oil circuit breakers consist each of three tanks bolted together, and the layout shown in Fig 17 is for duplicate switches and duplicate busbars The busbar enclosures are oil-filled, the oil level being maintained by an oil conservator It will be noticed that the potential transformers are removable by vertical isolation a transferable elevator likewise being used for this purpose

Instead of the usual bolts for holding the oil circuit breakers to the structure a system of clamping cams is used This should considerably shorten the time taken to remove a breaker for inspection or any other purpose

Naturally, such a form of switchgear as illustrated in Fig 17 must be connected up by means of cables These cables must in turn be connected to the overhead lines (if such are used) by some form of open-air gear Unless, therefore, the clearances on this latter are kept very large, it would seem that the advantages of total enclosure obtained with this switchgear are, to a certain extent, lost The complete logical solution is only obtained if this form of switchgear is used with systems employing armoured cables for transmission, in which case no open gear comes in the circuit at all

ISOLATED PHASE-TYPE SWITCHBOARDS

This type of gear, which has been mostly used in America, is a development of the separate phase idea mentioned on page 635 With it each phase is contained in an entirely separate and fireproof room

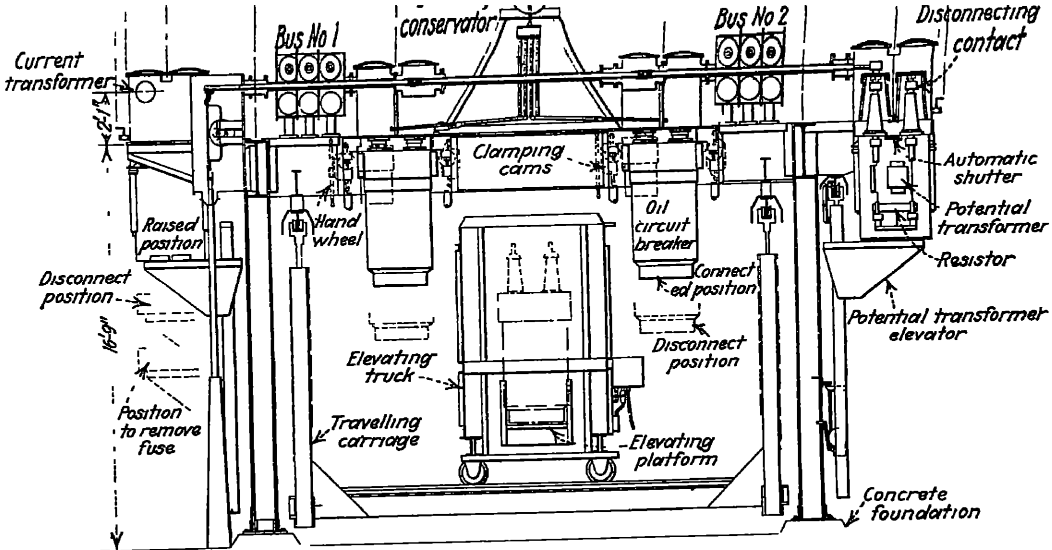


FIG 17 OUTDOOR METAL-CLAD (OIL-FILLED) SWITCHGEAR, 33,000 VOLTS

These rooms may be vertically underneath each other or arranged side by side, as in Fig 18 Care must be taken, as far as possible that there is no direct metallic connection between the phase rooms which would facilitate the drawing of an arc on one phase on to another phase Thus, it will be seen in Fig 18 that the steel operating mechanisms for the breakers are contained in special flumes separated from the phase rooms by thick walls The whole object of the scheme is to prevent the possibility of short-circuits occurring between phases

SHORT-CIRCUITS AND MECHANICAL FORCES ON BUSBARS

The conductors of any circuit carrying an electric current suffer a mechanical force in that direction tending to enlarge the area enclosed by the conductors. As this force varies as the square of the current flowing, on short-circuit it can assume a very large value, and cases are on record of busbars, having too weak supports, being violently forced out of their fastenings with, of course, disastrous results When designing a switchboard, therefore, it is necessary to determine the maximum mechanical forces the conductors will have to sustain, due to the passage of the maximum short-circuit current, and to design the supports accordingly

MECHANICAL FORCE ON PARALLEL CONDUCTORS

If d = distance in inches between the centres of the conductors,

I = amperes in conductor

Then—

$$\text{Force on bar in lb per foot run} = \frac{8\,1 \times 10^{-7}\, I^2}{d}$$

As an example, if I be 50,000 amp and d = 12 in

then the force on the bar per foot run is 168 lb Any other condition can be calculated by remembering that the force increases as the square of the current and, inversely, as the spacing

When applying this formula to any particular case, we have to determine the value of the short-circuit current This must be taken as the instantaneous initial peak value of the short-circuit Thus, if we were considering the short-circuit on an alternator having, say, 10 per cent reactance, then, if the full-load current of the machine is I_m amp, the value of current to be used in the above formula would be

$$2 \times 1.4 \times 10 \times I_m$$

The factor 1 4 is to get the peak value, as I_m is a root mean square value, and the factor 2 is to allow for doubling effect Actually, the figure so obtained would be on the top side, as the doubling factor is never quite as large as 2

CONSTRUCTION OF BUSBARS AND CONNECTIONS

Busbars and connections on switchboard are best made of hard-drawn copper bars While hard-drawn bars have a slightly lower conductivity than soft copper, the added rigidity which hard-drawn material provides renders its use desirable

BUSBAR SUPPORTS

These should, if the short-circuit current to be withstood is large, be arranged so that they are not subjected to forces at right angles to their axes, as they are naturally weakest in regard to forces in that direction, in other words, the axis of the support should be in the plane of the busbars This is illustrated in Fig 19, which is a particularly good arrangement It will be seen that the bars are supported in two

opposite directions, thus, the forces on the same, which may be up or down depending upon which phases are involved in the short-circuit, are counteracted Busbar supports are often made of porcelain, for the heaviest mechanical duty, however, bakelized paper, which withstands shock better, is a superior material, if the situation be a dry one Such a support is illustrated in Fig 20 The metal end-pieces are shrunk on, that is, they are bored out so that they just fit over when heated to about 350° C, on cooling they grip the bakelized paper tube tightly The metal fitting which holds the busbar is of gunmetal, to avoid hysteresis losses, the one forming the foot is of malleable iron

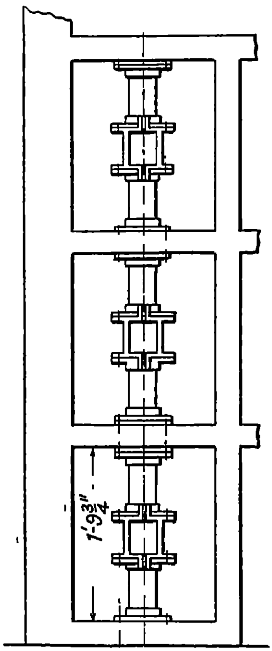


FIG 19 THREE-PHASE BUSBARS IN STONEWARE DUCTS, ARRANGED FOR MUTUAL SUPPORT

CURRENT-CARRYING CAPACITY OF BUSBARS AND CONNECTIONS

The B E S A specification No 159 (1925) contains the following requirements as regards the allowable heating of busbars and connections under working conditions, viz a maximum temperature rise of 30° C for single connections, and 35° C for multiple busbars The measurement of temperature may be made with a thermometer, placing the bulb in contact with the bars and covering it by a piece of waste These temperature rises are those of the hottest

spot, but places within $1\frac{1}{2}$ ft of instrument shunts (measured lineally along the conductors) are excluded, as the heat from the shunts, which run considerably hotter, is dissipated partly in the neighbouring metal.

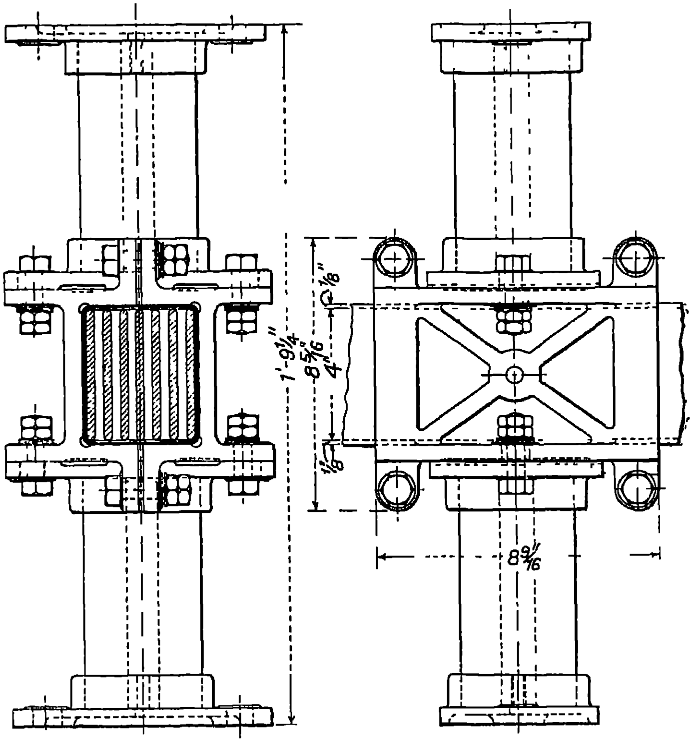


Fig 20 Double Busbar Insulator of Bakelite with Micanite Insulated Busbar

In order to guard against too great a reduction in mechanical strength (with small conductors) the B E S A specification also requires a maximum current density of 1000 amp per sq in

In order to keep within the limits of temperature rise specified above, it is necessary to vary the current density with the size of the bars and also according to whether continuous current or alternating current flows through them In the latter case, moreover, the periodicity of the current has to be taken into account The reason the current density has to be lower with alternating current than with continuous current is that with the former the current density is not uniform over the whole cross-section of the bar Because of a phenomenon known as the "skin effect," an alternating current always tends to flow more in the outer layers of a conductor than in the centre The effect is a maximum with conductors having a circular cross-section Hence, alternating current conductors are best made of thin rectangular strips The following table affords sufficient guidance in the great majority of cases when designing busbars It is based upon a maximum temperature rise of 30° C using hard drawn copper strips 4 in by ¼ in, spaced ¼ in between strips, and allows for the extra heating due to the proximity of other conductors, tee joints, etc, as in usual switchboard practice

TABLE GIVING MAXIMUM CURRENT DENSITY FOR CONTINUOUS LOADING OF BARE BUSBARS

Character of current	Busbar having a cross section of			
	5 sq in	4 sq in	3 sq in	2 sq in
D C (amp per sq in)	800	900	1000	1000 amp per sq in
25 periods ,,	750	850	950	1000 amp per sq in
50 periods ,,	700	800	900	1000 amp per sq in

Should the connections be covered with insulating material, such as several layers of tape or micanite

cured on, then the current densities in the above table must be lowered somewhat (about 10 per cent) If, however, the bars are in compound-filled chambers, a considerable difference is necessary, and the following table can be worked to—

TABLE GIVING MAXIMUM CURRENT DENSITY FOR CONTINUOUS LOADING OF COMPOUND INSULATED BUSBARS WITH ALTERNATING CURRENTS

Busbars having a cross-section of	Suitable current density (40 periods)
sq in	
8	360
6	420
5	450
4	500
3	600
2	720
1	1000

HEATING OF CONDUCTORS ON SHORT-CIRCUIT

In addition to the prevention of overheating of a conductor forming part of a switchboard when the normal current flows through it, another point which requires consideration is the sudden heating which will occur due to the passage of a short-circuit current It is necessary to watch this point, particularly in the case of small conductors connected to a heavy busbar If a short-circuit occur on such a light conductor near the busbar, the resistance in circuit may not be sufficient to prevent it assuming a dangerous temperature, in fact, such conductors may, under these conditions, be melted or vaporized practically instantaneously

As we are considering what happens in a very short period of time we can neglect the heat losses of the conductor due to radiation, heat conductivity, etc

The whole of the ohmic losses within the conductor are used to heat the mass of the conductor, and the temperature rise is limited only by the weight of the conductor and its specific heat

Let I be the short-circuit current passing through the conductor,

and C the cross-section of the conductor in square millimetres,

Then, $\left.\begin{array}{l}\text{temperature rise in degrees}\\ \text{centigrade per second}\end{array}\right\} = 0\ 005\left\{\dfrac{I}{C}\right\}^2$

Taking a concrete case of a conductor having 100 sq mm cross-section, if this be subjected to a short-circuit current of 50,000 amp, it would rise 250° C in $\frac{1}{5}$ sec, that is to say, it would constitute a source of danger

The matter is particularly important with current transformers In order to secure a sufficient volt-ampere output for current transformers used on low-current circuits they are sometimes wound with many turns of fine wire on the primary If such transformers are subject to sudden heating, as described above, they may actually explode On large switchboards, therefore it is good practice to use always single-turn, or straight-through type current transformers and to specify a minimum size of conductor (say 0 25 sq in), which may be connected directly to the busbars If fine-wire connections must be used they should be protected by a series resistance and some form of cut out

CURRENT TRANSFORMERS

Current transformers are mainly used on high-voltage circuits to operate instruments, relays, etc, which can then be at earth potential and safe to handle If the current transformer used for this purpose be a perfect

one, then the readings of the instrument fed by it would bear a constant ratio to the current on the primary side at all loads Such perfection, however, cannot be attained in practice, and, therefore, the use of current transformers entails a slight error in measurement. This error is of two kinds, viz a variation in numerical ratio between the currents in the primary and secondary, and a phase error due to the fact that the phase of the secondary current is not exactly 180° from the phase of the primary current This phase error is, however, only of importance with instruments of the wattmeter type B E S A specification No 81 sets up certain standards which these various errors may not exceed for different types of transformers

As regards the error in numerical ratio this may be corrected by simply altering the scale of the instrument, if this be of the ammeter type, in accordance with the ratio curve of the transformer With wattmeters, however, the phase error of the transformers introduces complications in that the effect of the phase angle of the transformer upon the accuracy of the instrument varies with the power-factor of the load being metered This is shown by the following table, which gives the error introduced in the reading of a perfect wattmeter if fed by a current transformer having a phase error of 1 degree—

Power factor of main circuit ($\cos \phi$)	Percentage error in wattmeter reading due to phase error of 1 deg in the current transformer
1	0
0 75	1 55
0 5	3 02
0 25	6 85
0	8

This phase error may be corrected for with some type of wattmeters by suitable adjustment The most convenient type of meter for this purpose is the induction wattmeter Dynamometer-type wattmeters are not generally capable of this adjustment and are, therefore, not so suitable for metering inductive loads in conjunction with current transformers

BALANCING OF CURRENT TRANSFORMERS

When current transformers are used for operating balanced protective schemes, it is necessary that the pair of transformers, which provide the samples of, say, incoming and outgoing current which are compared by the protective relays, should be balanced one against the other With some protective schemes, very accurate balancing is required if a reasonable stability (stability ratio) on heavy through faults is to be attained With biased protective schemes this is less necessary, as the biasing provides stability Nevertheless, even with biased systems one must be sure that the characteristics of the balancing transformers are similar This is especially difficult with balanced transformer protection With this the primary circuit transformer may be a single-turn bushing transformer (ratio, say, 200 to 0 5), while the secondary current transformer may have a ratio of 2000 to 0 5

In order to secure proper balancing it is necessary, first that the general physical shape of the two transformers should be similar, so that leakage effects shall be alike Further, the voltages given by the two transformers with corresponding loads should be equal and, moreover, the magnetic induction per square centimetre cross-section of the respective cores should be equal at full load

Let I_p be the primary current (at full load) of the main transformer, and I_s be the secondary current

Let N_p be the number of secondary windings on the current transformer on the primary side of the main transformer and N_s the number on the current transformer on the secondary side of main transformer

Let A_p and A_s be the respective cross-sectional areas of the cores of the respective current transformers

Let B = magnetic induction, lines per square centimetre, in the cores of both current transformers (i e. assumed equal in each)

Then we have— $N_pA_p\, B = N_sA_s\, B$

and $$\frac{N_p}{N_s} = \frac{A_s}{A_p}$$

That is to say, the cross-sectional area of the cores of the respective current transformers should be inversely proportional to the ampere-turns of the windings of the current transformers, i e in the above-mentioned case the cross-section of the core of the primary current transformer should be ten times larger than that of the secondary low-tension current transformer. The above calculation is not strictly accurate as among other things it assumes that the resistances of the secondary windings of both current transformers are equal

This condition can be met by suitably choosing the size of the wire used for the secondary windings the longer length of mean turn of the current transformer on the primary helps to attain this equality Again too, I_p and I_s may not increase proportionally to each other on short-circuit The calculation, however is sufficiently accurate for most purposes

POTENTIAL OR VOLTAGE TRANSFORMERS

The phase-displacement error of switchboard voltage transformers is generally small B E S A specification No 81 requires a maximum of 30 minutes and 60 minutes for classes B and C respectively, Class B being

for metering equipments requiring close accuracy, and Class C for ordinary industrial purposes

With all potential transformers there is a slight variation in ratio between no load and full load To secure maximum accuracy, the ratio should be adjusted to be the correct one when feeding a load or burden equal to that which the transformer will have to carry in practice Generally, however, the variation is very small and for commercial work can be neglected For 5000 volts and upwards potential transformers should always be oil immersed

THE PROTECTION OF POTENTIAL TRANSFORMERS

The protection of potential transformers is especially important when they are connected directly to busbars without the interposition of an oil circuit breaker Whenever possible they should be so connected that a circuit breaker is between them and the busbar Sometimes, however, this is not possible In this case they should be provided with isolating links so that they can be examined with safety To guard against insulation breakdowns of the high-tension windings, fuses must be provided

In order to limit the short-circuit current which will flow in the event of such breakdown, and to allow the fuses to rupture the circuit with safety, a series resistance on each pole should be included whenever the short-circuit current is liable to reach a dangerous value (see Fig 21) A suitable value for these resistances is about 40 ohms per 1000 volts, two such resistances being required for a single-phase, and three for a three-phase transformer

It is sometimes proposed to include this resistance within the fuse itself, that is, to rely upon a high-resistance fuse wire This is, however useless, as the arc

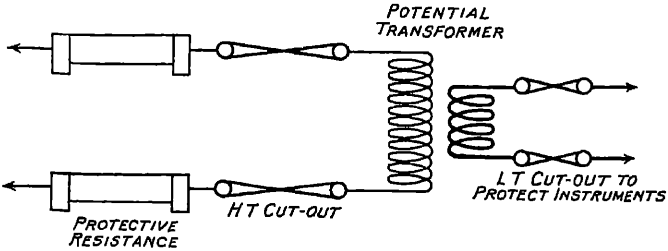


FIG 21 POTENTIAL TRANSFORMER WITH PROTECTIVE RESISTANCE

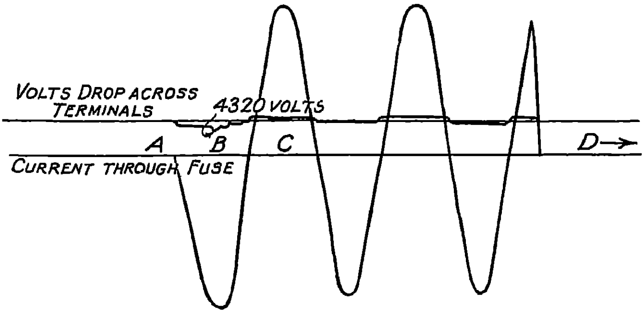


FIG 22 TEST ON FIBRE TUBE FUSE OF 79 OHMS RESISTANCE, WITH NO ADDITIONAL RESISTANCE IN SERIES

Tested at 6600 volts, 1970 amp maximum (Fuse blown to pieces, circuit opened manually)

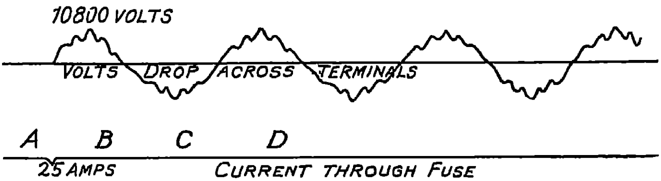


FIG 23 TEST ON FUSE OF 79 OHMS RESISTANCE, WITH 50 OHMS ADDITIONAL IN SERIES

Tested at 6600 volts, 25 amp maximum (Fuse opened circuit without visible disturbance)

resulting from the fuse blowing is of very low resistance, and the current which flows is, consequently, unlimited This is illustrated in Figs 22 and 23 It will be seen from Fig 22 that, although the fuse wire had a resistance of 79 ohms, the value which was effective in limiting the current was only about 5 ohms Against this, Fig 23 shows that the external resistance limited the current to an extent several times greater than its value in ohms would indicate

The fuses on the primary of a voltage transformer are useless to guard the same against overload, as it is not possible to use a sufficiently thin wire Overload must be prevented by suitable fuses on the low-tension side

BUSBAR ARRANGEMENTS

The busbars of a switchboard may be arranged either as single busbars, duplicate busbars, or ring busbars. For important installations either of the latter two may be employed, but in the large majority of cases the duplicate system is adopted

With 6600 and 11,000 volt generating station busbars it is not generally desired to run the different sets of busbars at different voltages In fact, if used for this purpose the busbars cannot be said to be duplicate ones The object of the duplicate busbars is mainly to allow of changing over and adjustment without cessation of supply, and for testing-out purposes when connecting up cables which have been shut down for repair For this latter reason the second set of busbars is sometimes termed the " hospital " bars

In some cases duplicate circuit breakers are used for each circuit as well as duplicate busbars This is a very extravagant arrangement and, having regard to present-day reliability of oil circuit breakers, is not generally justifiable If it be desired, however, to be able to

change over circuits from one busbar to the other without breaking circuit, then either duplicate circuit breakers must be provided or separate selecting isolating links

It is necessary in order to secure the full advantage of duplicate busbars to provide a coupling circuit breaker so that the two sets of busbars may be synchronized with each other With the coupling circuit breaker closed then a circuit may be changed over by closing its selector isolating switches on to both busbars, and then opening the isolator on that bus from which the circuit has to be disconnected This cannot be done with circuit breakers which are isolated by movement of themselves, as with metal-clad gear, and, of course, the isolating selector switches must not be interlocked.

SECTIONIZED BUSBARS

One method by which the maximum short-circuit current in a large station may be kept within bounds is to sectionalize the busbars by means of reactances. The various feeders should be allocated to the different sections of the busbars so that at full load the interchange of current between the sections is a minimum.

At light loads, when few generators are running, the busbar reactances may be cut out of circuit, as the possible short-circuit current is reduced by the fact that the total running plant is less If it be necessary to transfer large currents from section to section through the busbar reactances, these latter must be kept within a certain value, otherwise the volt drop across them will cause difficulties in running

A good arrangement of sectional busbars is shown in Figs 24 and 25 It will be seen that the individual busbar sections are connected together via two reactances in series and a tie bar The reactance of each coil is defined with regard to the kVA generator capacity

of the adjacent busbar section Thus the reactance of one of the coils would be B per cent if when the rated full generator load current of a section flows through it, the volt drop across the coil is B per cent of the busbar volts The total reactance between any two sets of busbars is thus 2B

Protective reactance coils should be arranged as already stated as far as possible, so that under normal

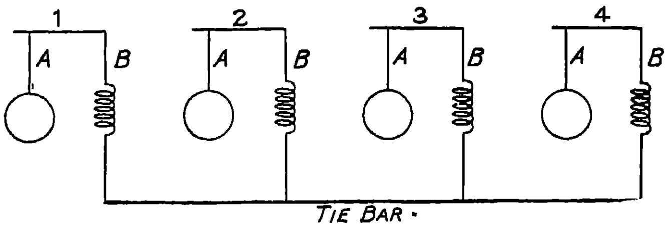


FIG 24 TIE BAR REACTANCE COILS

conditions little or no current passes through them Although the actual watt loss in a reactance coil is small, nevertheless it absorbs kVA, and, therefore, tends to limit the output of the generators From this point of view the tie-bar arrangement of reactances (see Fig 25) is good, as if the feeders and generators are suitably proportioned no current need pass the reactances It is not always possible to attain this, however, and sometimes current must pass the reactances Let us assume the maximum current which will ever pass a reactance is half the full-load current of a complete bus section , also that the total reactance between each bus section is 50 per cent, reckoned upon the total capacity of a bus section Thus, the individual reactance coils in Figs 24 and 25 would be 25 per cent Let us consider two busbar sections by themselves, as in Fig 26

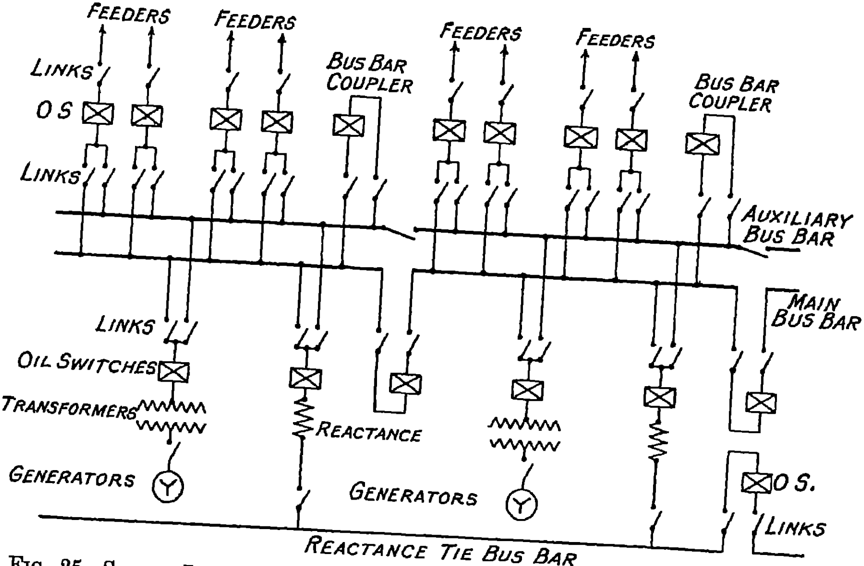


FIG 25 SINGLE LINE DIAGRAM OF CONNECTIONS OF TIE BAR REACTANCE COILS

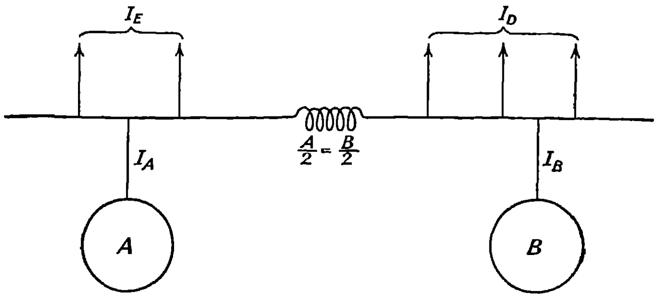


FIG 26 TWO BUSBAR SECTIONS OF EQUAL REACTANCE ($A = B$)

Separated by a 50 per cent reactance

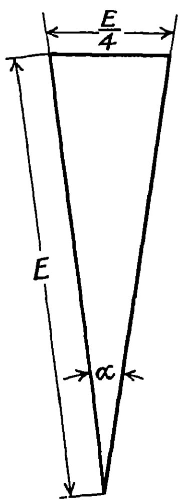


FIG 27 VOLTAGE RELATIONSHIP BETWEEN TWO SECTIONS OF BUSBARS

Separated by a 50 per cent reactance based on the busbar section capacity and passing half full current of a busbar section, the two sections being equal in voltage

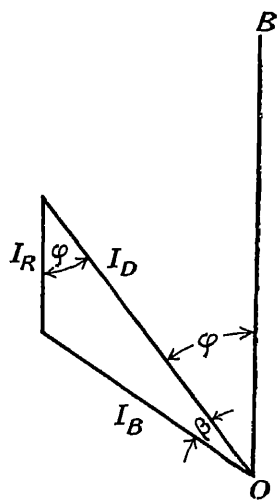


FIG 28 CURRENT AND VOLTAGE ON HEAVILY LOADED BUSBAR SECTION

(Approximate)

The reactance of the generators are A and B respectively and $A = B$ The reactance between the two busbars = 50 per cent Then, if half the full load flows from A to B the volt drop across the reactance will be $\frac{E}{4}$, it being arranged that busbar volts of A equals busbar volts of B

The diagram (Fig 27) gives the voltage conditions of the two busbars The angle α is the phase difference between the voltage of the two busbars We can approximately set

$$\sin \alpha = \frac{\frac{E}{4}}{E} = \tfrac{1}{4}$$

$$. \quad \alpha = 14 \text{ deg}$$

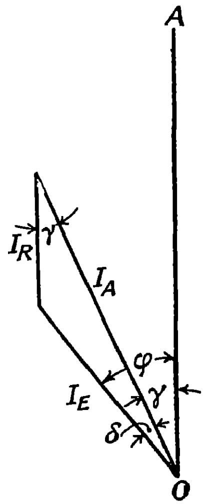


FIG 29

We desire to find to what extent the power factors of the respective generators are altered under these conditions Assume the power factor of the load on the feeders E and D is 8, i e $\cos \varphi =$ 8 and $\varphi = 37$ deg

Referring to Fig 28, OB represents the busbars volts of the B busbar I_R = current through the reactance which for an approximate calculation can be drawn parallel to OB as it lags 90 degrees relatively to the voltage across the reactance *

We then have

$$\frac{\sin \beta}{\sin \varphi} = \frac{I_R}{I_B}$$

* This means that a "Watt" current is being transferred from bus to bus through the reactance

Then, if I_B is, say, twice I_R

$$\sin \beta = \frac{\sin \varphi}{2} = 0\ 3$$

$$\text{and } \beta = 17 \text{ deg}$$

Therefore, the angle of lag of the current in generator B relative to the busbar volts is

$$37 \text{ deg} + 17 \text{ deg} = 54 \text{ deg}$$

and the power factor at which the generator B is running is 59

Considering now generator A, the approximate vector diagram is given in Fig 29

I_E is the current in feeders E lagging 37 degrees behind the busbar volts

$$\frac{\sin \gamma}{\sin \delta} = \frac{I_E}{I_R}$$

If $\quad I_E = \text{say } 2I_R$

$$\text{then } \frac{\sin \gamma}{\sin \delta} = 2$$

and we can set approximately

$$\gamma = 2\delta$$

But as $\gamma + \delta = \varphi$

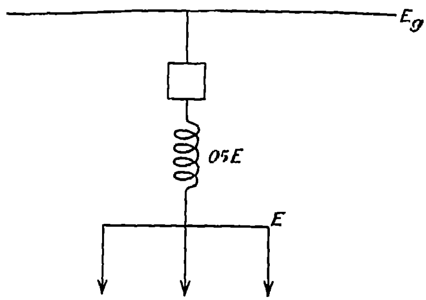


Fig 30 Group Feeder Reactance Coil

it will be seen that the angle of lag of the current in the generator A is about two-thirds of 37, i e its power factor is 91

It follows that in order to transfer current from the lightly loaded busbar to the heavily loaded, the power factor of the generator on the lightly loaded bars must be put up, and that on the heavily loaded bars goes down There is a slight difference in phase between

the respective busbars, but the voltage of the busbars can be equal to each other Thus. voltage regulation from each busbar is unaffected Naturally, there must not be a path of low reactance in the network between

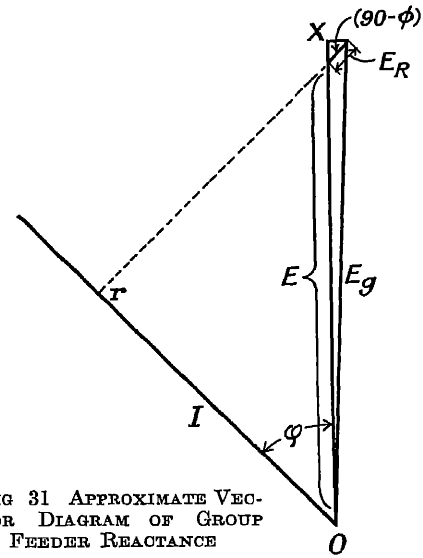


FIG 31 APPROXIMATE VECTOR DIAGRAM OF GROUP FEEDER REACTANCE

the two busbars, as this would have the effect of short-circuiting the busbar reactance

GROUP FEEDERS

In order to keep down the necessary size and cost of feeder breakers it is sometimes arranged to group a number of the feeders on an auxiliary busbar, using for these moderately large feeder circuit breakers The auxiliary bar is connected to the main bus through a group reactance coil and a circuit breaker equal in size to the others on the main bus (see Fig 30)

In order to avoid difficulties with voltage regulation it is necessary to keep the value of such a feeder reactance small, say, 5 per cent, i e when the full current of the group passes through it the drop is 5 per cent of the group busbar volts In order to send the current through the group reactance the main busbar must be somewhat higher in voltage by an amount depending upon the power factor of the load

Referring to the diagram (Fig 31), E is the auxiliary busbar voltage and I the total full load of the grouped feeders

$E_R = 0\ 05E$ (if the reactance be a 5 per cent one), and E_R is at right angles to OI E_g is the main busbar volts If a line be drawn from the upper end of E_g perpendicularly to the continuation of E, we get the line OX, which approximately is equal to E_g

We then get the following approximate equation—

$$E_g = OX = E + E_R \{\cos(90 - \varphi)\}.$$

Thus, if $\varphi = 45$ degrees, i e power factor of load be 70 per cent,

then $\cos(90 - \varphi) = 0\ 7$,

and the main busbar volts would have to be $7 \times 5\% = 3\frac{1}{2}\%$ higher than the group bus , also, of course, the power factor of the current flowing from the main bus is somewhat less

The above approximate rules are useful to quickly determine the effect of various reactances in the circuit For exact work, naturally, the correct vector diagrams must be drawn

SECTION XII

D.C AND LOW TENSION A.C. SWITCHGEAR

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SECTION XII

D.C. AND LOW TENSION A.C. SWITCHGEAR

FUSIBLE CUTOUTS

FUSES are commonly employed on direct current circuits up to 600 volts and alternating current circuits up to 650 volts For duty up to 100 amp at 250 volts the standard requirements are covered by British Standard Specification No 88, but the dimensions of many makers' products do not conform to those given in this specification

GENERAL CONSTRUCTION AND OPERATION

A large variety of fuses are manufactured but each incorporates a fusible element, which is heated to melting point when an excess current flows The current is then broken either by the molten metal flowing out of the holder, as in the older types of fuse, or by the volatilized metal being absorbed either by an asbestos pad or a filling powder as in the more modern types of fuse In other patterns of cutout the fuse wire follows a tortuous path from terminal to terminal with barriers inserted between, the object of this and the other constructions mentioned being to quench the arc formed when the fusible element blows, and thus interrupt the circuit

APPLICATION OF FUSES

On account of their relatively low cost, fuses are widely used for power and lighting circuits in both factories and homes, and provided the fuse is connected

wired, and applied correctly, satisfactory protection is afforded. For power station and sub-station duty, however, some discretion must be exercised as, by reason of the general construction of fuses and the proportion of the parts, the maximum short-circuit current which they will interrupt is definitely limited

As a guide it is recommended that unless economy is essential the maximum working current for which fuses are employed should be limited to 300 amp , or, under special circumstances, 500 amp , either direct current or alternating current At these currents the size of the fusible element is such that a considerable amount of molten metal has to be absorbed when the fuse blows, and any failure may be attended by damage to material or injury to life

Further, fuses should not be connected direct to busbars which are supplied by large capacity generators, either alternating current or direct current, or heavy power transformers, as such power units give very heavy currents on short-circuit, which may destroy a fuse attempting to open the circuit under fault conditions

In cases where economic conditions render it necessary to use fuses, then they should be grouped and supplied through an oil circuit breaker or an air circuit breaker, according to whether the current is alternating current or direct current These devices, being of larger interrupting capacity, afford support for the fuses, so that if the latter fail to open the circuit it is broken by the operation of the air or oil circuit breaker, as the case may be

In general, the rupturing capacity of domestic type cutouts can be taken as 30 times their fusing current, that of industrial cutouts 60 times their fusing current, and that of heavy duty cutouts 100 times their fusing current

N E C S cartridge fuses are tested to rupture 10,000 amp

When it is known, or where calculations show that the maximum short-circuit current will exceed these values, then it is necessary to use oil or air circuit breakers to control the circuit or to back up the fuses according to circumstances

TYPES OF FUSE

Open Type Porcelain Handle Fuse. In this type of cutout the fusible element is contained in a rewirable porcelain handle Figs 1 and 2 illustrate a fuse of this pattern Except for quite small currents, the fusible element consists of a number of wires in parallel which pass through asbestos tubes, and are fixed to terminals on a metal contact at each end of the handle. The ends of the asbestos tubes are left open so that when the fuse blows the metal is ejected and the arc thus extinguished

The porcelain holder which encloses the asbestos tubes is fitted with a jug handle designed so that the fuse may be removed or replaced without danger of contact with live metal

PARTICULARS OF CARTRIDGE FUSE SHOWN IN FIG 2

Current rating (amperes)	Fig No	A		B		C		D		E	
		in	mm	in	mm	in	mm	in	mm	in	mm
75	1	$6\frac{3}{4}$	172	$5\frac{3}{4}$	146	$8\frac{1}{4}$	210	$2\frac{1}{8}$	54	$\frac{11}{32}$	11
100	1	$6\frac{3}{4}$	172	$5\frac{3}{4}$	146	$8\frac{1}{4}$	210	$2\frac{1}{8}$	54	$\frac{11}{32}$	11
150	2	8	203	$7\frac{3}{4}$	197	$9\frac{5}{8}$	245	$2\frac{7}{8}$	73	$\frac{17}{32}$	14
200	2	8	203	$7\frac{3}{4}$	197	$9\frac{5}{8}$	245	$2\frac{7}{8}$	73	$\frac{17}{32}$	14
250	2	8	203	$8\frac{1}{4}$	210	$9\frac{5}{8}$	245	$2\frac{7}{8}$	73	$\frac{21}{32}$	17
300	2	8	203	$8\frac{1}{4}$	210	$10\frac{3}{4}$	273	$2\frac{7}{8}$	73	$\frac{21}{32}$	17
350	2	8	203	10	254	$10\frac{3}{4}$	273	$3\frac{7}{8}$	99	$\frac{29}{32}$	23
400	2	8	203	10	254	$10\frac{3}{4}$	273	$3\frac{7}{8}$	99	$\frac{29}{32}$	23
500	2	8	203	10	254	$10\frac{3}{4}$	273	$3\frac{7}{8}$	99	$\frac{29}{32}$	23

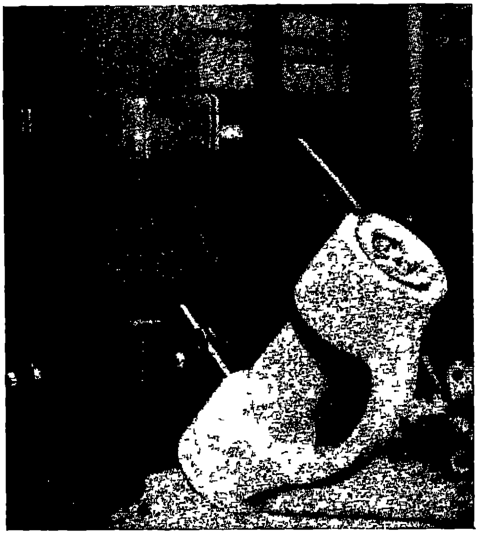


FIG 1 PORCELAIN HANDLE FUSIBLE CUTOUT

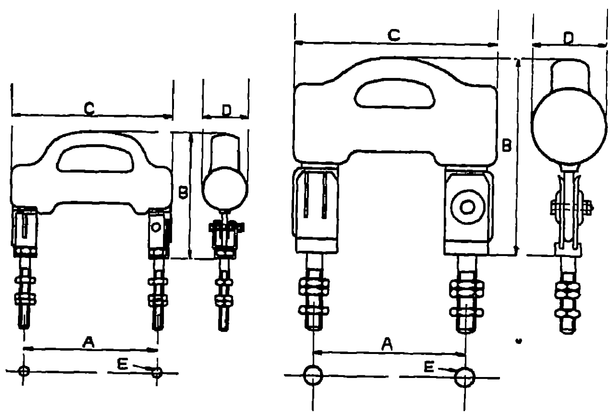


FIG 2

The contacts on the handle engage with fixed jaws of the self-aligning type, the bottom jaw being fitted with a hinge pin, so that the fuse may act as a switch should it be desired to interrupt the circuit on load Cutouts of this type are made for currents up to 500 amp at 650 volts

Protected Type Porcelain Handle Fuse. This type of fuse is similar to that described above except that provision is made to protect an operator from the molten fusible element when the fuse blows

Figs 3 to 7 illustrate a fuse of this pattern

It will be noted that the ends of the fuse holder are enclosed by a porcelain cap, which also covers the contacts so that the fused metal is confined and is absorbed by the asbestos tubes, and all live metal is entirely covered

This type of fuse is more expensive than the open type previously described, and is employed where the service conditions demand the improved construction

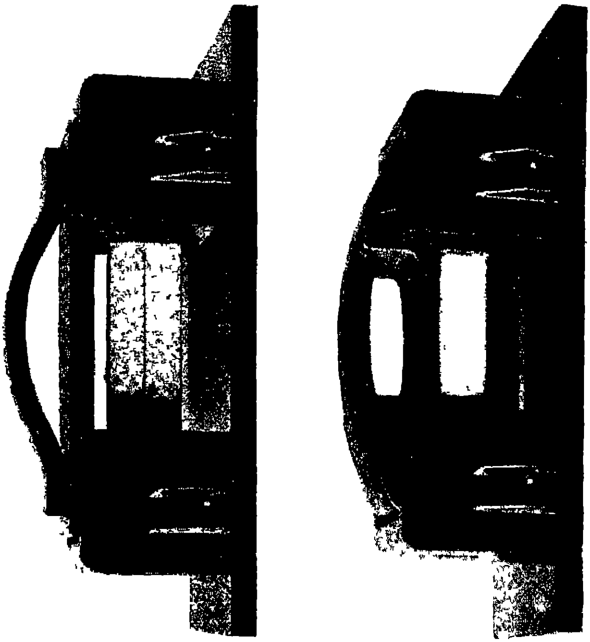
Cutouts of this type are made for currents up to 700 amp at 600 volts

Cartridge Fuses. Cartridge fuses are widely employed in America for distribution work, but only to a minor extent in Great Britain and other countries

Fuses of this type have standardized dimensions and tests, the standard article being known as the National Electrical Code Standard Approved Fuse

In general, the cutout consists of a fusible element mounted in a fibre or moulded insulation container which is filled with a mixture of plaster of Paris, marble dust, magnesium silicate, and chalk, these substances tending to damp the arc when the fuse blows The ends of the container are fitted with ferrules, which, in the case of the larger current rating, have a knife blade for engaging with lever clip contacts on the switchboard panel

In certain makes of cartridge fuse, the links are so designed that the irregular path of the current tends



Figs 3 and 4 Protected Type Fusible Cutout
(Side view)

to create a magnetic field which assists in interrupting the circuit

The objection to cartridge fuses is that of the difficulty of rewiring them, or, alternatively, the cost of new fuses if blown fuses are discarded In some of the later patterns of cartridge fuse, rewiring has been

facilitated so that this can be carried out reasonably conveniently by the user

Cartridge fuses are also employed for the protection of instrument and control circuits on alternating and

FIGS 5 AND 6 PROTECTED TYPE FUSIBLE CUTOUT
(Front view)

direct current switchboards For this duty the container is usually a glass tube with nickel plate ferrules for front of panel mounting

The N E C S fuses previously described are made for duty up to 600 amp at 600 volts, and instrument fuses for 30 amp at 250 volts

Bimetal Fuses. In cases where a fuse is required which will blow on relatively small overloads, Hope's

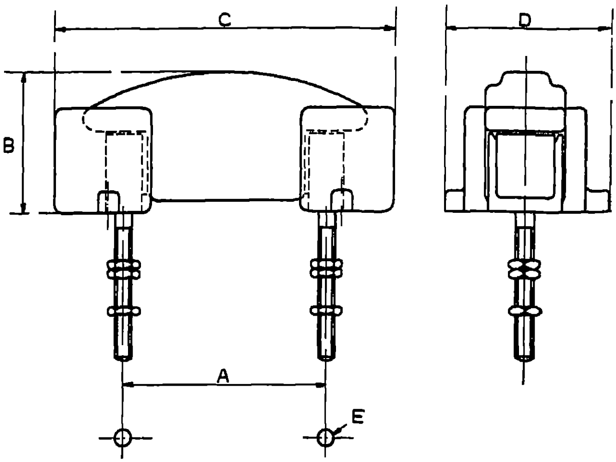


FIG 7 PROTECTED TYPE FUSIBLE CUTOUT

PARTICULARS OF FUSE SHOWN IN FIG 7

Volts	Current rating (amperes)	A		B		C		D		E	
		in	mm	in	mm	in	mm	in	mm	in	mm
250	5–15	$1\frac{7}{16}$	37	$1\frac{13}{16}$	46	$2\frac{7}{16}$	62	$\frac{3}{4}$	19	$\frac{1}{4}$	6
600	20–35	$3\frac{7}{16}$	87	$2\frac{3}{16}$	56	$4\frac{3}{4}$	121	$1\frac{1}{8}$	29	$\frac{9}{32}$	7
600	50–75	$4\frac{1}{16}$	103	$2\frac{1}{2}$	63	$7\frac{1}{16}$	179	$3\frac{1}{4}$	82	$\frac{11}{32}$	9
600	100	$5\frac{3}{4}$	146	4	102	$9\frac{5}{8}$	245	$4\frac{1}{2}$	114	$\frac{13}{32}$	11
600	150	$5\frac{3}{4}$	146	4	102	$9\frac{5}{8}$	245	$4\frac{1}{2}$	114	$\frac{17}{32}$	14
600	200	$6\frac{5}{8}$	168	$4\frac{3}{4}$	121	$11\frac{1}{2}$	292	$5\frac{1}{2}$	140	$\frac{21}{32}$	17
600	300	$6\frac{5}{8}$	168	$4\frac{3}{4}$	121	$11\frac{1}{2}$	292	$5\frac{1}{2}$	140	$\frac{25}{32}$	20

bimetal fuse may be employed The fusible element consists of an alloy fuse wire with a copper core In

fusing, the alloy core first melts off, leaving the small section of copper to break the circuit

Fuses of this type are claimed to be able to carry 90 per cent of their fusing current indefinitely

Enclosed Fuses. For distribution and domestic work totally enclosed fuses are often employed, the fuses being mounted either singly or in multiple in a cast-iron box

This class of fuse is also used for power stations and sub-stations in situations where porcelain or cartridge fuses mounted on a switchboard panel would not be suitable

For purposes of safety the containing box must be earthed, and if one pole of the supply system is also earthed a potential will exist between the fuses and their case For this reason fuses mounted in a metal box must be of a reliable construction and of high rupturing capacity in order that the arc developed when the fuse blows shall not spread to the case and thus destroy it

Fuse Wires. For small currents up to 25 amp pure tin, or tin lead alloy wire, is used for the fusible element. Wires of these metals are, however, mechanically weak, and pass through a pasty stage before actually blowing Due to this pasty condition, the fuse often fails prematurely through vibration

On this account tinned copper wire or strip is or should be, used for circuits above 25 amp The ratio between the normal carrying current and blowing current is approximately 2 1, i e 100 per cent overload the table shown on page 680 giving the size of wires commonly employed for various circuit ratings.

It should be particularly noted that cartridge fuses blow at 50 per cent above their normal rated current, the lower fusing current, as compared with porcelain handle fuses, being due to the fusible element being entirely enclosed and unventilated

SIZES OF FUSE WIRE

Maximum working load	Copper wire	Strands in parallel	Maximum working load	Coppe wire
amp	S W G		amp	S W (
3	36	1	75	20
5	36	2	100	20
8	36	3	150	18
12	36	6	200	16
20	22	1	250	16
30	20	1	300	16
40	18	1	350	15
50	20	2	400	14
60	16	1	500	13

PARTICULARS OF SWITCHES SHOWN IN F

Amp	DIMENSIONS IN INCHES										
	A	B	C	D	E	F	G	H	J	N Whit	I
200	7 1/4	10 3/4	5 3/4	3/4	1	10 1/4	4	1 5/8	2 1/4	1/2	
300	8 1/2	11 7/8	6 3/8	7/8	1 3/8	12	4 1/4	1 5/16	2 3/4	5/8	1
500	10 5/8	13 1/8	7 1/8	1 1/8	2 1/4	14 3/8	4 1/4	2 1/4	4 1/8	7/8 11 T P I	1
800	12	16 1/4	8 3/4	1 1/4	2 3/4	16 1/4	4 1/4	3	4 5/8	1 11 T P I	1
1200 D C	13 1/2	19 3/4	10 3/4	1 3/4	3 1/2	18 1/4	5	3 5/8	5 5/8	1 1/4 11 T P I	1
1200 A C	13 1/2	19 3/4	10 3/4	1 3/4	3 1/2	18 1/4	5	3 5/8	5 5/8	1 1/2 11 T P I	1
1600 D C	12 1/8	20	11	2	2 3/4	16 7/8	6	3 1/4	4 7/8	1 1/2 11 T P I	1
1600 A C	12 1/8	20	11	2	2 3/4	16 7/8	6	3 1/4	4 7/8	1 3/4 11 T P I	1
2000 D C	13 7/8	20 1/2	11 1/2	2 1/2	3 1/2	19 3/8	7	4	6	1 3/4 11 T P I	2
2000 A C	13 7/8	20 1/2	11 1/2	2 1/2	3 1/2	19 3/8	7	4	6	2 1/4 11 T P I	2

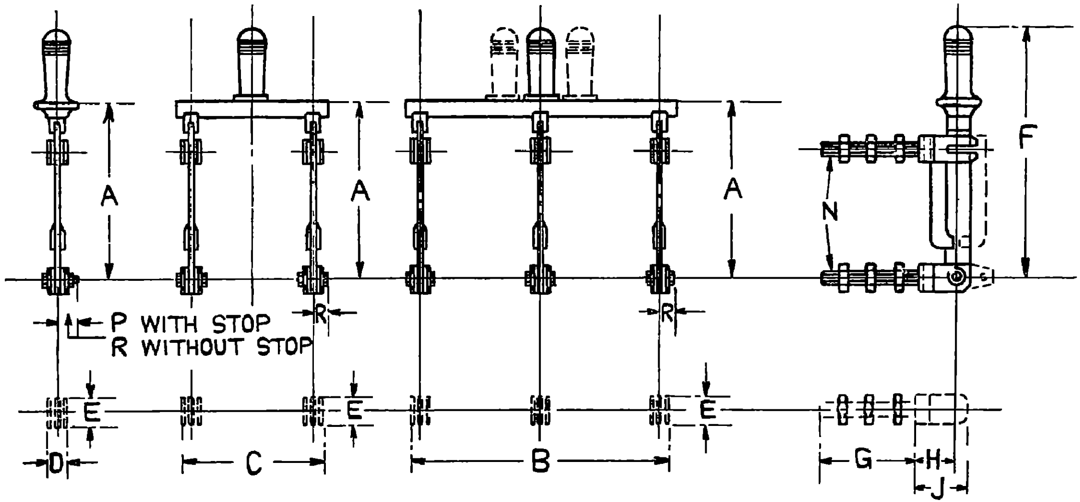


Fig 8 Quick Break Lever Switch

AIR BREAK KNIFE SWITCHES

Air break knife switches are used for making and breaking alternating current and direct current circuits and also for isolating apparatus such as circuit breakers, fuses, etc , from the source of supply

British Standard Specification No 109-1923 covers the general requirements and includes tables which set out the standard current ratings, the standard size of stud and the screw thread on same, and the standard dimensions for switches up to 400 amp capacity

For currents up to 2000 amp the conventional air break switch consists of one or more blades of hard drawn copper, hinging on spring clips at one end and engaging with similar spring clips at the other

The terminal studs are circular and are fitted with hexagon brass nuts to take either copper strip or cable connections.

Figs 8 to 10 illustrate a range of air break switches of this type

In some makes of switch the circular stud and contact block are omitted, and the contacts take the form of parallel copper strips, the front extension of which forms the spring clips, the part extending at the back of the panel forming the terminal connections

This construction requires a rectangular hole in the switchboard panel for the contacts, but has the advantage that by reason of the absence of joints, a lower temperature rise is secured

In general, switches up to 2000 amp for direct current are designed with contact densities ranging from 50 to 70 amp per square inch, which give the temperature rises of 20° C and 30° C laid down in B S S. 109

For alternating current duty, particularly on heavier currents, skin effect makes it necessary to increase the stud diameter as indicated in Table II of B S S 109

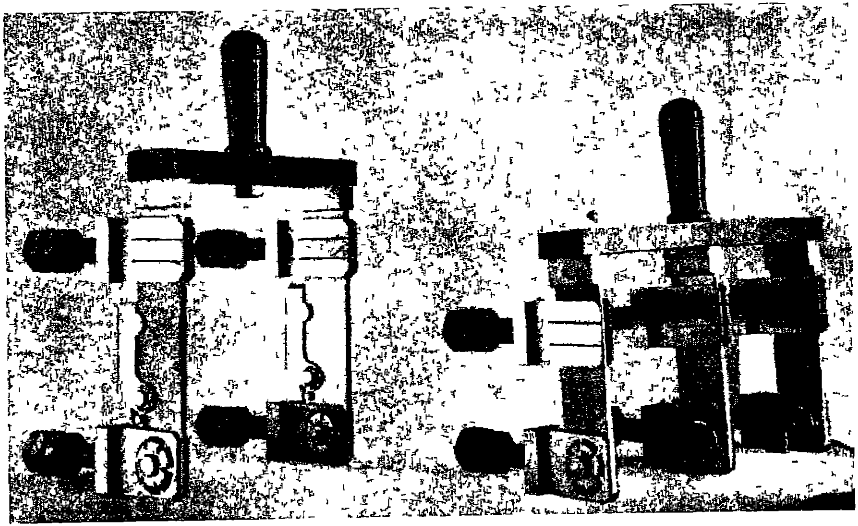


Fig 9 Quick Break Lever Switches

For currents above 2000 amp it is now usual to employ laminated blade lever switches in which the blades are in multiple, and engage with strip contacts, the necessary contact pressure being obtained by screws, flanged washers, and an insulating handle by which

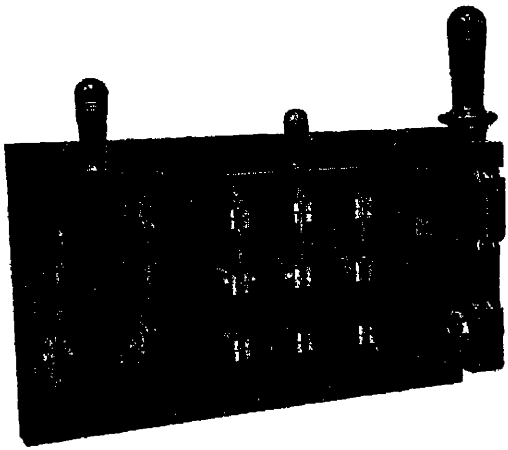


FIG 10 SLOW BREAK LEVER SWITCHES

the contact is tightened when the switch is closed Figs 11 and 12 illustrate switches of this type

SLOW AND QUICK BREAK SWITCHES

Slow break switches, i e switches in which the speed of breaking is dependent upon the operator, should only be used for isolating purposes, except for small currents and then for pressures not exceeding 250 volts

Where load current has to be interrupted, quick break switches should be employed, i e a switch in which

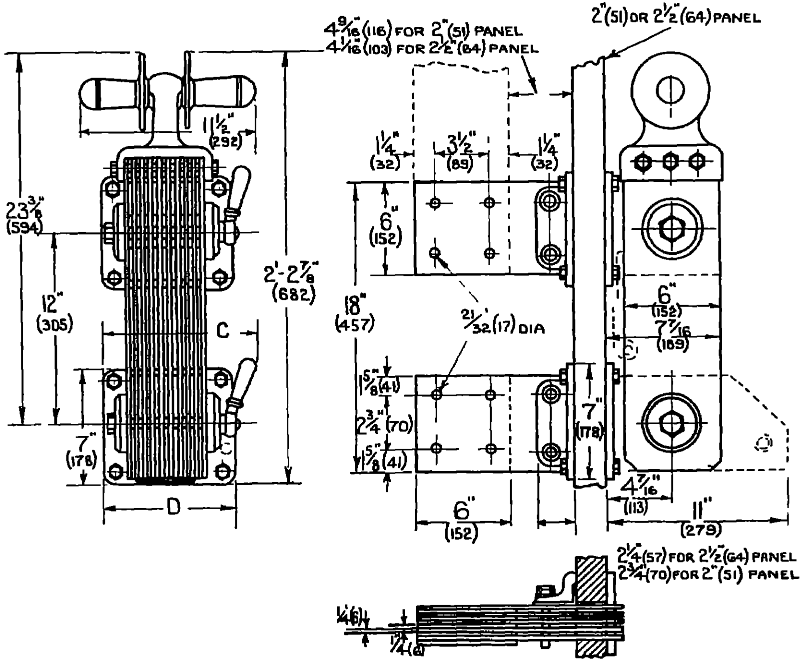


Fig 11 Laminated Blade Lever Switch

PARTICULARS OF SWITCH SHOWN IN FIG 11

Number of blades		Capacity amp	Dimensions							
			A		B		C		D	
Stud	Switch		in	mm	in	mm	in	mm	in	mm
2	3	3000	$\frac{7}{8}$	22	3	76	$6\frac{1}{2}$	165	$4\frac{1}{2}$	114
3	4	4000	$1\frac{3}{8}$	35	$3\frac{1}{2}$	89	7	178	5	127
4	5	5000	$1\frac{7}{8}$	48	4	102	$7\frac{1}{2}$	191	$5\frac{1}{2}$	140
5	6	6000	$2\frac{3}{8}$	60	$4\frac{1}{2}$	114	8	203	6	152
7	8	8000	$3\frac{3}{8}$	86	$5\frac{1}{2}$	140	9	229	7	178
9	10	10000	$4\frac{3}{8}$	111	$6\frac{1}{2}$	165	10	254	8	203

a quick break is ensured independently of the speed of action of the operator

The quick break is usually secured by means of a follower blade attached to the main blade by a spring, the follower being retained in the clip contact when the main blade is withdrawn, but leaving the clip at a high speed when the spring tension is sufficient to overcome the retaining pressure

With suitably designed switches smartly operated, currents up to 2000 amp at 600 volts may be safely interrupted, but burning is liable to take place on the switch contacts, so that for currents above 1000 amp air or oil circuit breakers are preferable

It should be particularly noted that with double throw switches only relatively small currents may be broken on the bottom throw, as the arc drawn follows the path of the blade, and sustained arcing may occur In general, it is not safe to interrupt more than 25 per cent of the switch rating on the bottom throw, particularly if the circuit is inductive

Use of Switches. Considered from the standpoint of switchboard practice, it is customary to employ air-break knife switches on both alternating current

and direct current panels On direct current panels, switches are used in series with air circuit breakers,

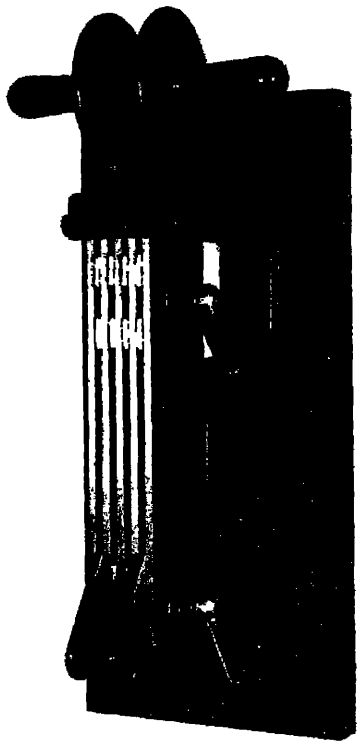


FIG 12 LAMINATED BLADE LEVER SWITCH

firstly, with the object of isolating the breaker from the busbars to allow maintenance work, and, secondly, to permit of paralleling This is carried out on lever switches, the breakers first being closed so that they

are ready to trip should any abnormal condition develop when the machine is connected to the busbars

Switches are also connected in series with fuses serving both to make and break load current, and also to isolate the fuse for rewiring

Air break switches may be used for similar duty

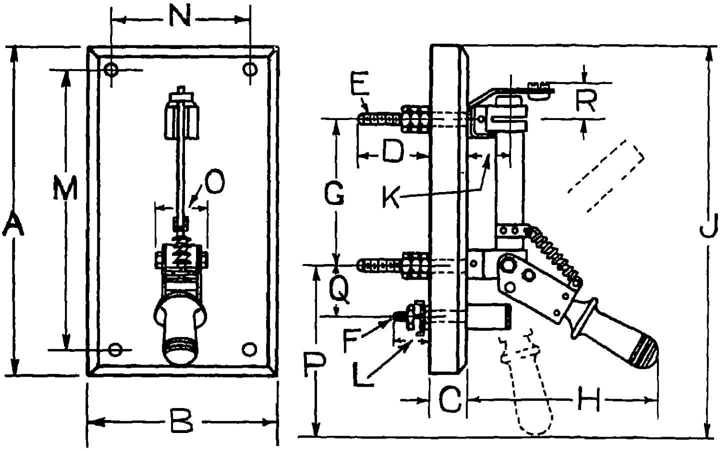


Fig 13 Field Breaking Switch with Discharge Contact

on alternating current switchboards, but oil circuit breakers are generally used, except for very small capacity circuits.

FIELD DISCHARGE SWITCHES

In order to avoid a pressure rise it is necessary when opening the field circuit of a generator to connect a discharge resistance across the field terminals This is accomplished by an air break switch having an additional contact See Figs 13 to 15

The construction is such that the extra contact is

PARTICULARS OF SWITCH SHOWN IN FIG 13

Amp	Dimensions in inches and millimetres																
	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P	Q	R
200	$12\frac{1}{2}$ 318	4 102	$1\frac{1}{4}$ 32	$2\frac{3}{4}$ 70	$\frac{1}{2}$ 13	$\frac{5}{16}$ 8	5 127	$6\frac{5}{8}$ 168	$14\frac{5}{8}$ 371	$1\frac{5}{8}$ 41	2 51	$10\frac{3}{4}$ 273	$2\frac{1}{4}$ 57	$1\frac{3}{4}$ 45	$5\frac{7}{8}$ 149	$1\frac{7}{8}$ 48	$1\frac{3}{16}$ 30
300	$12\frac{1}{2}$ 318	4 102	$1\frac{1}{4}$ 32	3 76	$\frac{5}{8}$ 16	$\frac{5}{16}$ 8	6 152	$7\frac{3}{8}$ 187	$15\frac{5}{8}$ 397	$1\frac{15}{16}$ 49	2 51	$10\frac{3}{4}$ 273	$2\frac{1}{4}$ 57	$2\frac{1}{16}$ 52	$6\frac{7}{8}$ 175	$2\frac{1}{4}$ 57	$1\frac{1}{4}$ 32
500	$17\frac{1}{2}$ 445	5 127	$1\frac{1}{2}$ 37	$2\frac{3}{4}$ 70	$\frac{7}{8}$ 22	$\frac{5}{16}$ 8	$7\frac{1}{4}$ 184	$10\frac{1}{4}$ 260	$20\frac{1}{2}$ 521	$2\frac{3}{4}$ 70	$1\frac{3}{4}$ 44	$15\frac{1}{2}$ 384	3 76	$2\frac{1}{4}$ 57	$8\frac{1}{4}$ 210	$3\frac{1}{8}$ 79	$1\frac{7}{8}$ 48

made before the blade leaves the main contact, so that the field circuit is never actually broken

Suitable discharge resistances have an ohmic value

FIG 14 FIELD BREAKING SWITCH

1 0 to 1 5 times the field resistance, and are capable of carrying the maximum field current for 15 secs.

MISCELLANEOUS TYPES OF SWITCH

Control Switches. For the remote electrical operation of alternating current oil circuit breakers, field rheostats, governor control motors, etc , control switches

are employed, these taking the form of miniature barrel controllers Fig 16 illustrates a switch of this type

Such switches may be fitted with red and green indicating lamps to show the position of the device controlled, and also with an interlocking key which can only be removed when the control switch has been moved to the " off " position and locked in that

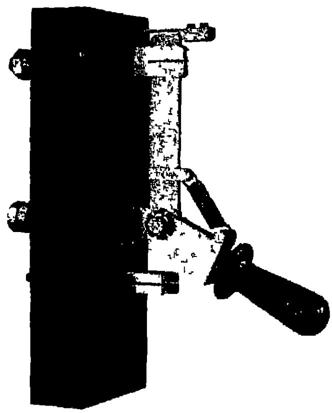


FIG 15 FIELD BREAKING SWITCH

position Having gained the key, access may then be obtained to the switchgear cell with the safeguard that the oil circuit breaker is open and locked off

Ammeter Switches. On three-phase alternating current circuits it is sometimes necessary to read the current on all three phases, but it is not always convenient to employ three ammeters for the purpose In the circumstances an ammeter switch is employed in conjunction with the secondaries of the circuit current transformers

Fig 17 illustrates a switch of this type, and Fig 17*a* shows a diagram of the connections

Direct current ammeter switches are not recommended, as, since the resistance of the ammeter winding

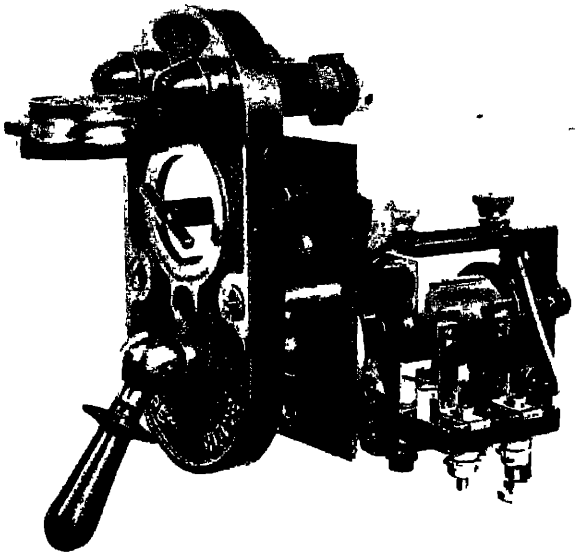


FIG 16 CONTROL SWITCH WITH KEY INTERLOCK AND INDICATING LAMPS

is so small and the potential available only the millivolt drop across the shunt, any contact resistance on the ammeter switch would cause incorrect readings on the instruments

Voltmeter Switches. When it is desired to employ a voltmeter to read the pressure of two or more circuits, a voltmeter switch is used of the type illustrated in Fig 18

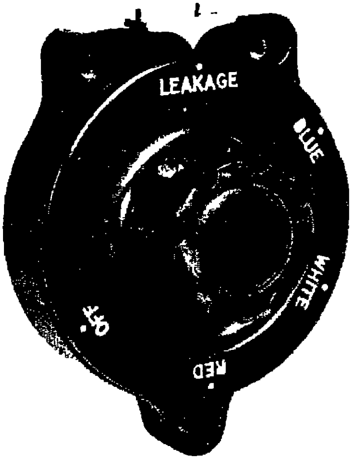


FIG 17 THREE PHASE AMMETER SWITCH

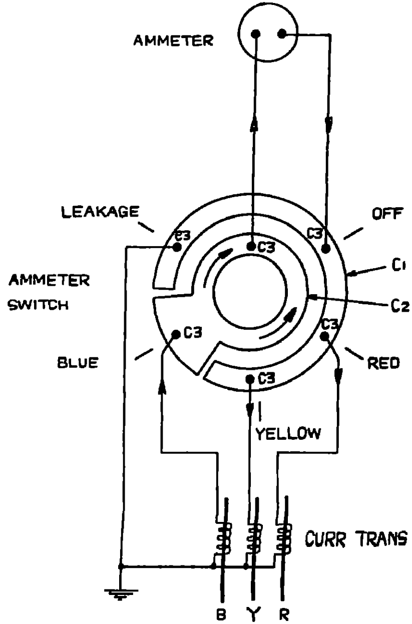


FIG 17a CONNECTIONS OF AMMETER SWITCH

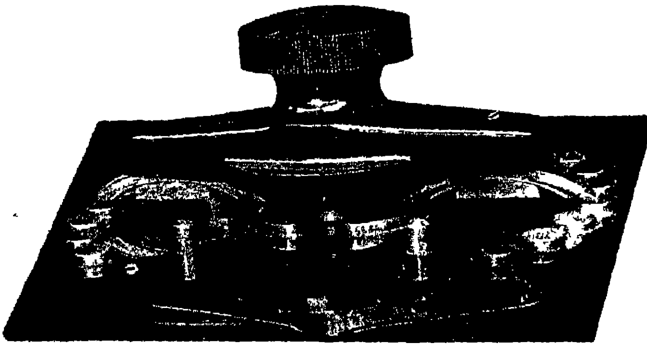


FIG 18 VOLTMETER SWITCH

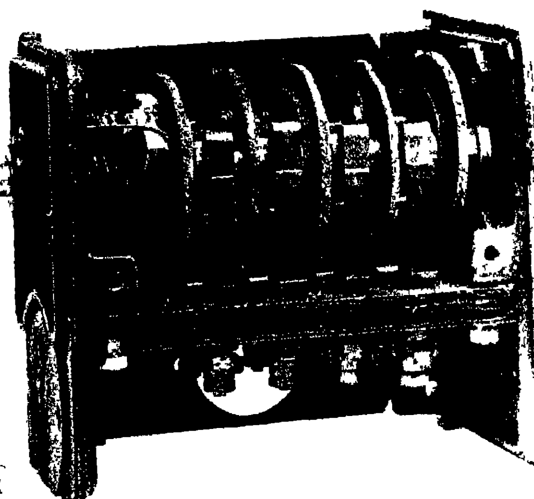


FIG 19 AUXILIARY SWITCH

In a well designed switch the moulded handle is arranged to shield the operator from accidentally touching the contact studs

Auxiliary Switches. Auxiliary switches are fitted to

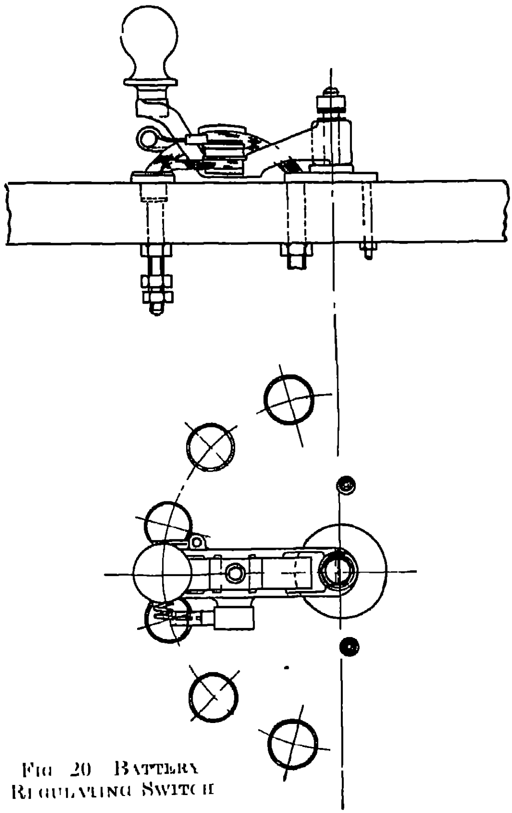


FIG 20 BATTERY REGULATING SWITCH

many switchgear devices for indicating, alarm, interlocking, protective, control and other circuits, and such switches serve a very important purpose

For this reason, auxiliary switches of substantial mechanical design are now employed, although the actual current handled may be relatively small Fig 19 illustrates a typical auxiliary switch suitable for fitting to air circuit breakers, oil circuit breakers, isolating switches, and operating mechanism, the design being such that it is capable of practically universal application

In essence this switch is a miniature barrel controller built up of units, each unit comprising two poles Currents up to 25 amp can be made and broken, and the switch can be arranged as either a slow- or a quick-break as may be required

Battery Switches. Batteries are commonly used in power stations and substations for the operation of oil circuit breakers and their indicating lamps, and in emergency for pilot lighting

To obtain the normal voltage under all conditions of charge, 61 cells are used for 110 volts, and 133 cells for 240 volts, the end cells being connected to a battery regulating switch

Fig 20 illustrates a switch of this type

This is merely a simple dial switch, but with an auxiliary brush connected through a resistance to the main brush, so that the battery circuit is not broken nor a cell short-circuited when passing from one stud to the next

AIR CIRCUIT BREAKERS

Air circuit breakers are widely used for direct current circuits and occasionally for low tension alternating current duty where economic conditions do not justify oil circuit breakers

The standard requirements are set out in the British Standard Specification No 110, 1923, which covers standard current ratings, standard range of settings

for overload, and other attachments, and standard temperature rises

In general, air circuit breakers of various makes are

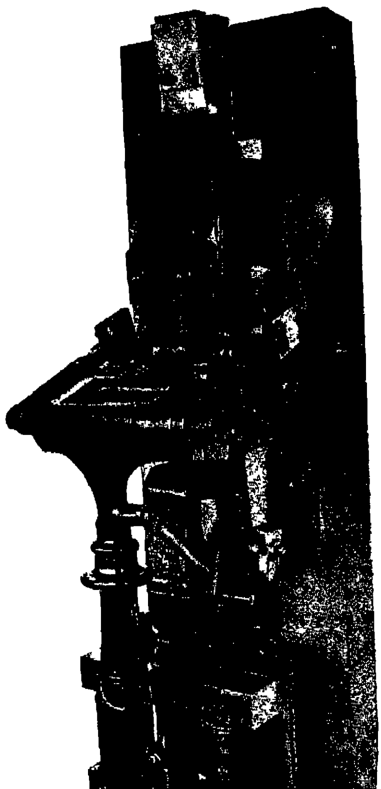


FIG 21 AIR CIRCUIT BREAKER
(With attachments)

of more or less similar construction, consisting of an upper and a lower contact block fixed to the switchboard panel, and a moving brush contact which bridges under pressure the stationary contacts In addition to the main contacts auxiliary copper contacts are provided to protect the main contacts, and also springs carrying carbon contacts on which the final break is made

Fig 21 and 22 illustrate typical air circuit breakers which incorporate many good features in design

To obtain proper contact pressure the link mechanism is designed to toggle and the links are held in position by a hardened latch, which is tripped by the operation of the various automatic release devices

Brushes. Two types of brush are commonly employed, one known as the butt type in which the laminations bear practically end-on to the contact block, and the second a wiping brush contact, in which the laminae make a considerable angle to the block

In the former design the laminations make an angle of a few degrees from 90° to the block, so that when the brush is pressed home the laminations spread slightly, giving a wiping action, and ensuring that each beds independently on the block Further, the face of the brush is cut back at a small angle so that the top lamination makes contact first, ensuring a uniform pressure throughout the whole contact surface

By reason of the end-on contact of this type of brush a very considerable contact pressure may be exerted, ranging from three to eight ounces per ampere, equal to, say, a ton on a 6000 amp breaker

With the second type of brush contact mentioned such pressure cannot be applied, as, due to the angle which the laminations make with the contact block, each laminae merely spreads more when the pressure is increased

To secure proper contact, adequate pressure is necessary and experience has shown that the butt type brush

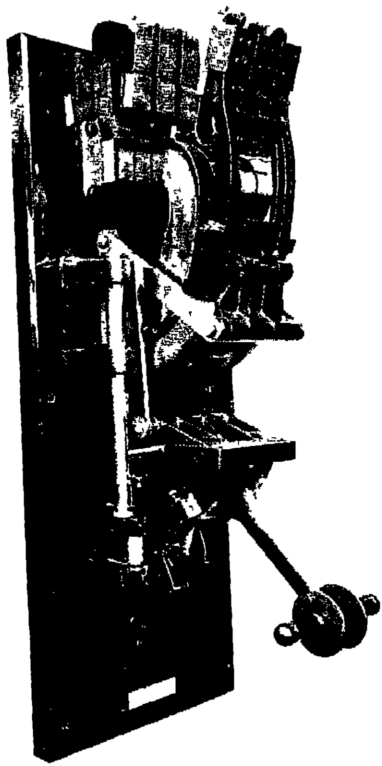


FIG 22 HEAVY CURRENT AIR CIRCUIT BREAKER

contact gives reliable service, and that it can be run at a higher density than any other type of brush

In general contact densities of 500 amp per sq in

from 100 to 10,000 amp breakers will give a temperature rise on full load within the limits specified by B S S 110

Auxiliary Contacts. The auxiliary contacts previously mentioned serve to protect the main contacts against burning when opening an overload or short circuit The construction of the contact carrier is such that the auxiliary copper contacts break after the main contact, and the carbon auxiliary contacts last Carbon is employed for the reason that it does not readily vaporize, and the contact wear is, therefore, relatively small When the arc is drawn its resistance increases as it lengthens, reducing the current gradually, the arc being finally extinguished when it has extended to such a length as to render it unstable

In the type of breaker illustrated in Figs 21 and 22 the carbon blocks are surrounded by a soft iron shoe, termed a magnetic ear This has a definite magnetic blow-out action by virtue of the field set up which tends to pull the arc stream towards the carbon

In order that the arc shall be extinguished as quickly as possible, experience has shown that for circuits up to 650 volts the optimum length of break measured between carbon tips is approximately as follows—

amp	Length of Break
100	$2\frac{1}{2}$ in
200/300	$3\frac{1}{4}$,,
400/500	$4\frac{1}{8}$
600/1000	$4\frac{1}{2}$,,
2000/4000	5
5000/6000	$6\frac{1}{2}$
8000/10000	8

The average operating time of a circuit breaker, measured from the incidence of the fault to the final interruption, varies from ·10 to 15 sec according to the size of the breaker

For service above 650 volts it is necessary to increase both the length and speed of break, or, alternatively, to use magnetic blow-out or high speed circuit breakers, which are described in a separate section of this publication To afford safety to the operators, all circuit breakers for duty above 650 volts are remote operated, either electrically or mechanically

Attachments. Circuit breakers may be fitted with any one or a combination of the following automatic attachments

Overload trip with or without time delay device
Reverse current trip
Under voltage trip
Shunt trip
Tripping interlock between single pole breakers

All modern circuit breakers are designed so that these attachments are operative immediately the carbon contacts touch, i e the breaker cannot be held in against a short circuit or an overload This is known as a trip-free feature

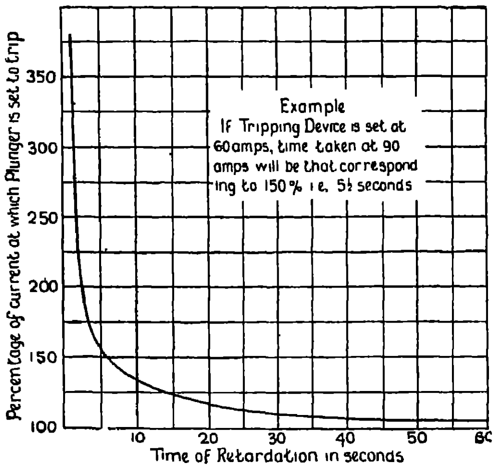
Overload Attachments consist in general of an iron circuit linked with a series coil having two or more turns up to 1200 amp , or merely surrounding the lower stud on 2000 amp breakers and above At predetermined currents according to the setting, the field produced in the iron circuit either raises a plunger or lifts a hinged armature, the movement of which frees the latch holding the breaker closed

The range of calibration usually extends from 75 to 250 per cent of the rated current

Time Lag Attachments To prevent a breaker being tripped by a momentary overload, a time delay device, either of the fixed or adjustable type, can be fitted to the overload attachment Such devices usually consist of a dash pot and plunger, which is either retarded by oil or by air escapement

Fig 23 shows the characteristic curve of a typical adjustable time lag

Reverse Current Attachments usually consist of a magnetic circuit excited by a series and also a potential coil, the fluxes produced with current in the normal



TIME LAG CURVE

FIG 23

direction being such as to hold a hinged armature against a stop When the direction of current reverses, however, the armature is repelled and its movement frees the latch holding the breaker closed

Fig. 24 shows the principle of operation of the device described above

An attachment similar to that illustrated will operate at 10/15 per cent of the breaker rating, which affords adequate protection against motoring on either a direct current generator or rotary convertor

Under-voltage Attachments are employed to trip a

circuit breaker should the circuit voltage fall below a predetermined value, usually between 50 and 65 per cent of normal

The device usually consists of an electro-magnet

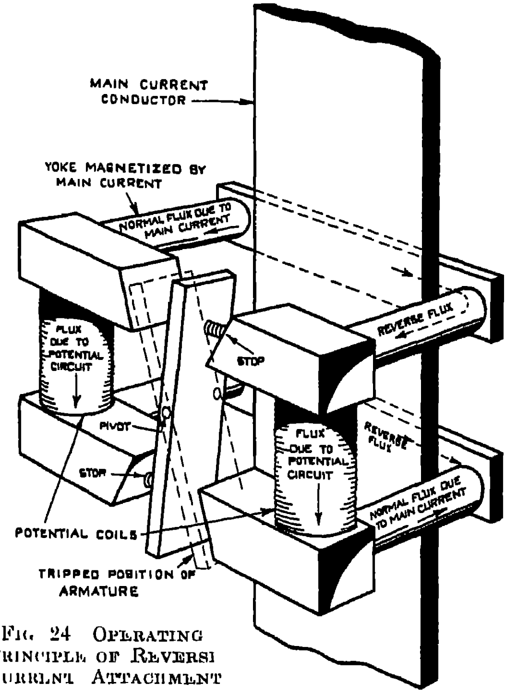


FIG. 24 OPERATING PRINCIPLE OF REVERSE CURRENT ATTACHMENT

holding up a weight, which is released by gravity when the voltage falls below the value mentioned, the movement of the weight freeing the latch which holds the breaker closed

On breakers up to 500 amp the weight has to be reset by hand, but on breakers of 800 amp and above the weight is mechanically lifted when the breaker handle is reset for closing.

Shunt Trips are fitted to circuit breakers to enable them to be tripped from a remote point from overspeed contacts on rotary convertors, or from over-current or reverse current relays when such are used to obtain more sensitive setting than can be secured by direct fitted attachments

The construction is similar to that of undervoltage attachments except that the electro-magnet raises a plunger when current is applied, the movement of the plunger being used to trip the breaker

Shunt trips usually operate down to 50 per cent of the circuit voltage

The shunt trip coil must be disconnected by an auxiliary switch or by the breaker when it opens

Interlocks may be fitted to two or more single pole breakers to ensure simultaneous tripping, although each pole may be closed independently

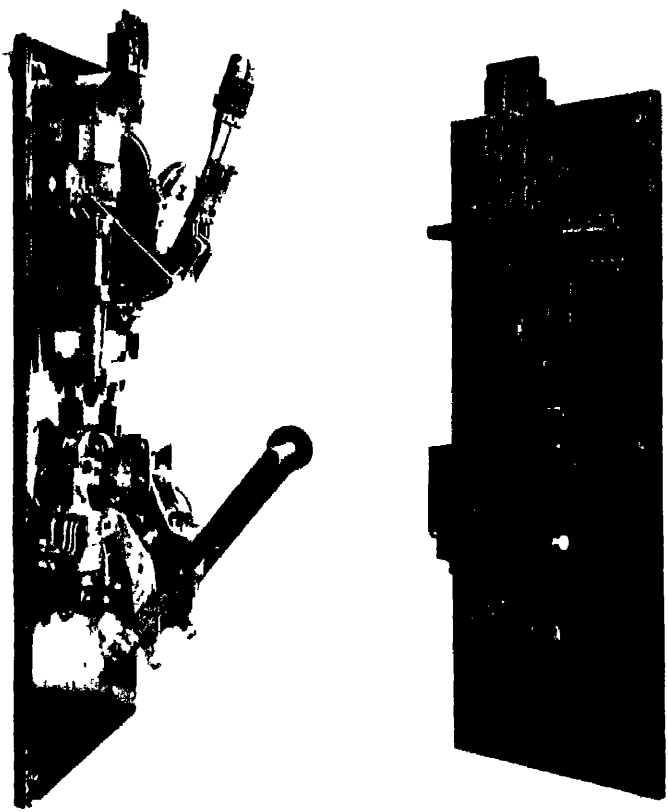
Operating Mechanisms. Circuit breakers up to 6000 amp can conveniently be manually operated, but for 8000 amp breakers and above, direct current solenoid mechanisms are preferable on account of the magnitude of the closing effort required

Such mechanisms are frequently fitted to smaller breakers where remote electrical operation is required Figs 25 and 26 illustrate a 6000 amp breaker complete with its solenoid

Solenoids are usually designed for operation from a battery, the loading ranging from $7\frac{1}{2}$ kW for closing a 2000 amp breaker, to 15 kW for an 8000 amp breaker

Where hand operation is preferred, either a plain or spade handle is fitted, or on the larger capacities a detachable handle is employed

On both types of closing mechanism buffers are fitted to the breaker to brake the opening forces and to prevent the stored energy in the moving parts throwing



FIGS. 25 AND 26. SOLENOID OPERATED AIR CIRCUIT BREAKERS

an undue stress on the frame Such buffers take the form of leather stops, buffer springs, or, on the larger capacities, air dashpots

Mounting of Circuit Breakers. The action of an air circuit breaker when opening an overload on short circuit has already been described, reference being made to the attenuation of the arc as the contacts separate The arc drawn, however, may rise 12 to 24 in above the arcing contacts, so that circuit breakers should always be mounted at the top of a panel, preferably in a position such that the arcing contacts project just above the panel In this position the arc does not burn the face of the panel and is able to rise freely and be cooled quickly, and thus be speedily extinguished For similar reasons ample headroom should be provided above air circuit breakers, particularly heavy current traction breakers, above which all constructional steelwork must be covered, as one pole of a traction system is earthed Where breakers are mounted at close centres intermediate barriers either of slate or "Uacolite" are sometimes fitted, and for traction switchboards it is also customary to cover the panel fixing bolts with insulated caps and to screen the framework at the top of the panel by uacolite covers

Circuit breakers should not be mounted low down on a switchboard panel, as, when opening an overload, the arc may cause damage to material and risk to life

LOW TENSION OIL CIRCUIT BREAKERS

The general construction and design of oil circuit breakers is dealt with in a separate section of this work, so reference will only be made to heavy current breakers which are peculiar to low tension alternating current work

For currents up to 1500 amp high tension oil circuit breakers are commonly used for low tension duty,

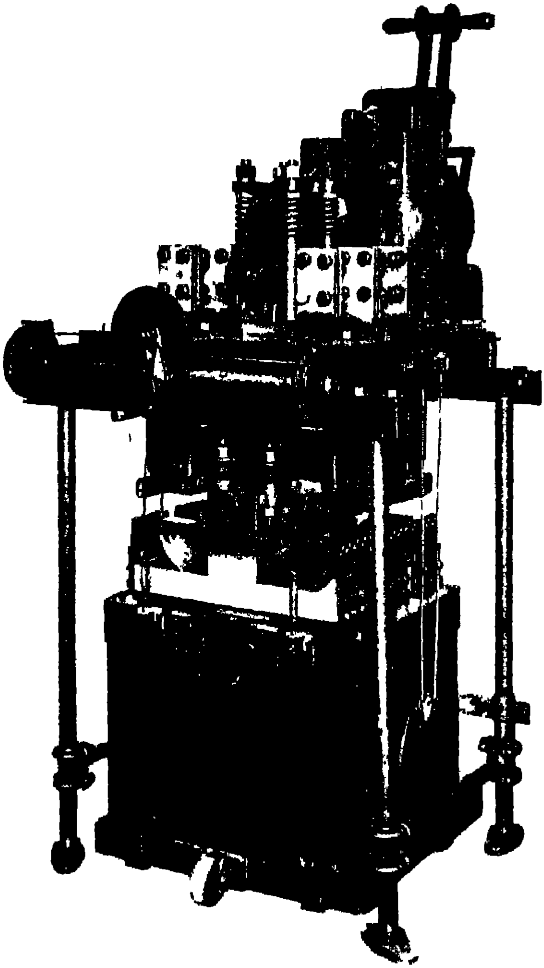


FIG. 27 HEAVY CURRENT LOW TENSION ALTERNATING CURRENT OIL CIRCUIT BREAKER
(*Brush Contacts*)

chiefly for reasons of manufacturing convenience For currents of 2000 amp and above, however, specially designed breakers for service up to 650 volts are employed Fig 27 illustrates typical breakers for this duty

Breakers of this type are virtually air circuit breakers mounted on a slate base, but pointing downwards, and projecting into an oil tank By reason of skin effect very low current densities must be used, and the terminal studs are constructed of laminated copper strip

In addition, the tanks are preferably constructed of sheet brass and the links and mechanisms of nomag iron or phosphor bronze

The practical and economic limit to the current rating of a three-pole switch is 3000 amp, and for currents above this it is customary to employ two or more three-pole breakers in parallel, operated by a common mechanism

Oil circuit breakers of the type described can be designed for a rupturing capacity of 25,000 kVA, or say, a maximum plant capacity of 5000 kVA For heavier short circuit duty up to 50,000 kVA, brush contacts are replaced by finger contacts, the slate top is replaced by a nomag iron top, and it is necessary to use a steel tank

Fig 28 illustrates a breaker of this type having a current rating of 3000 amp

The design of heavy current low tension alternating current breakers presents a real problem as, by reason of the fact that copper oxidizes if run at a temperature exceeding 55° C, any local heating speedily produces cumulatively bad contact

The main and arcing contacts have, therefore, to be designed to have ample contact and cross sectional area, and ample contact pressure must be provided In addition, magnetic material should not be employed

except where strength necessitates its use for the tank Tanks with corrugated sides, to increase the radiating area, are sometimes adopted, and radiating tubes, as

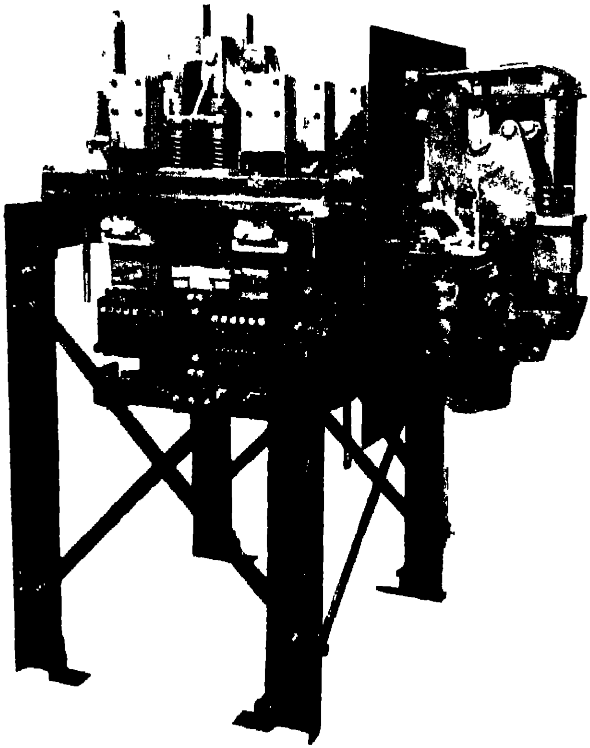


FIG. 28 HEAVY CURRENT LOW TENSION ALTERNATING CURRENT CIRCUIT BREAKER
(Finger Contacts)

fitted to transformer tanks, have been successfully applied in some designs

In general heavy current low tension alternating current oil circuit breakers must be installed so that

they are adequately ventilated, as, since the permissible temperature rise is 40° C, a considerable amount of heat has to be dissipated The practice of fitting such breakers in enclosed cubicles, or at the back of a switchboard, cramped by cables, screens or with a narrow

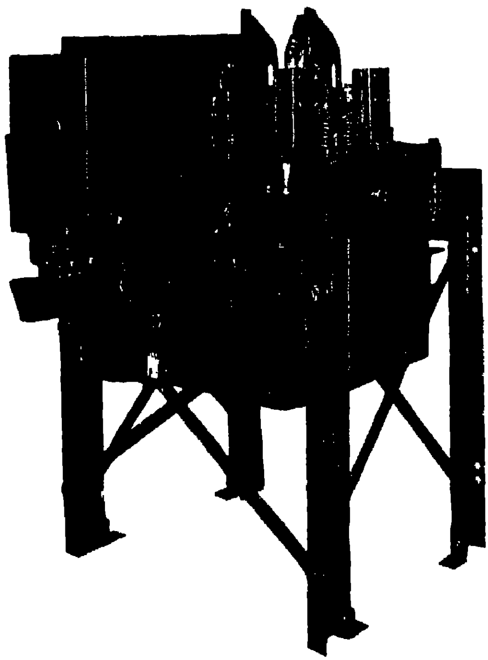


FIG 28A HEAVY CURRENT CIRCUIT BREAKER

gangway, is strongly to be deprecated, as in positions of this kind proper ventilation is impossible

Reference may be made to B S S 116 for the general requirements in respect to oil circuit breakers, and for the tests and temperature rises applicable

ALTERNATING CURRENT AND DIRECT CURRENT SWITCHBOARDS

General Construction. The word "switchboard" is a generic term which covers an assembly of switchgear devices, usually mounted on a slab or slabs of insulating material and connected electrically so as to enable a circuit such as a generator, a transformer, or feeder to be controlled

The slabs are referred to as switchboard panels, which may be constructed of any one of the following materials—

Slate | Silumimite
Marble | Sheet steel
Sindanyo (ebony asbestos)

The characteristics of these alternative materials are shown in the following table—

PROPERTIES OF INSULATING MATERIALS

	Sindanyo	Silumimite	Slate	Marble
Density	1 61	1 83	2 8	2 75
Moisture absorption	0 27-0 20	0 10–0 34	0 18%	006–1%
Compression strength in lb per sq in	13,100	12,380	15,000	11,800–10,000
Shear strength in lb per sq in	5500	4380	4000	3200
Impact strength in foot lb per sq in	3 4	1 52	1 7	0 25
Electrical strength in volts per mil — Through material Along laminae	 41 5 25	 64 17	 4–5	 31
Arc resisting properties	Not arc resistant	Not arc resistant	Arc resistant	Arc resistant
Resistance to heat	Only moderately heat resistant	Only very moderately heat resistant	Heat resistant	Heat resistant
Machining properties	Good	Good	Poor	Very poor

It may be assumed that 95 per cent of switchboard panels are constructed of slate, marble only being used where conditions are such as to require its greater electrical strength, or, in some cases, where good appearance is desired regardless of expense

As Welsh slate is increasingly difficult to obtain, and Portuguese slate has relatively poorer insulating qualities, a greater use is now being made of synthetic moulded panels, the best known material being sindanyo, which is composed of Portland cement and asbestos fibre moulded under hydraulic pressure

Such material being stronger, particularly in impact, than slate or marble, it may safely be used in smaller thickness of slab, and on this basis the present-day cost of sindanyo panels is equal to, or slightly less than, slate panels of equivalent linear dimensions

As the electrical strength is also very much greater, it follows that sindanyo is becoming more extensively used by switchboard manufacturers, and it is considered that within a few years slate may no longer be employed

For certain classes of work sheet-steel panels are also finding favour on account of their low cost, the ease with which they may be cleaned and refinished and their relatively small weight for a strength corresponding to that of an equivalent slate panel

Steel panels are however, limited mainly to alternating current switchgear where the devices comprise oil circuit breakers, current transformers, and isolators which have earthed metal supports For direct current switchgear, the expense of insulating lever switches, fuses, and circuit-breaker studs and contacts from the metal panel makes the use of sheet steel prohibitively costly

Finish. Switchboard panels may have any one of the following alternative finishes—

1	Stoved black enamel	Polished
2	Sprayed black lacquer	Matt
3	Linseed oil treated	Matt
4	Cellulose enamel	Polished

Until recently polished black enamel was the accepted standard finish for slate panels, but cellulose enamel is gradually being substituted, as this gives a better wearing surface, which is improved by cleaning, whereas black stove enamel becomes scratched, and eventually wears to a dirty brown hue

Sprayed black lacquer, or marine finish, as it is termed, and also oiled finish are employed for industrial switchboards, where a polished finish would be out of keeping with the surroundings These finishes are also used for export work, where it is difficult to transport and re-erect polished panels without damage

Strength of Panels. In order to prevent fracture, either in manufacture, or shipment, or in service, experience has shown that for a given thickness, panels should not exceed the widths shown in the following table—

Thickness	Maximum width of panels		
	Slate	Marble	Sindanyo
in	in	in	in
$\frac{3}{4}$	16	10	20
1	20	14	28
$1\frac{1}{4}$	28	18	36
$1\frac{1}{2}$	36	24	40
2	40	36	48
$2\frac{1}{2}$	48	42	—

As a further guide it should be noted that the

minimum recommended thickness of panel for air and oil circuit breakers is as follows—

	Minimum Thickness		
	Slate	Marble	Sindanyo
	in	in	in
Air circuit breakers up to 3000 amp	1½	2	1¼
,, ,, ,, solenoid operated	2	2½	1½
,, ,, ,, 4000/6000 amp	2	2½	1½
,, ,, ,, solenoid operated	2½	—	2
,, ,, ,, 8000/10,000 amp	2½	—	2
,, ,, ,, solenoid operated	3	—	2½
Oil circuit breaker, 500 amp	1½	2	1¼
,, ,, ,, 800/2000 amp	2	2½	1½

Where more than one circuit breaker is mounted side by side on a common panel, then the next size thicker panel is usually desirable

Framework. Switchboard panels may be carried on a variety of different types of framework, but the two common forms of support are—

Pipe framework
Angle-iron framework

In the former case the upright and wall stay consist of 1¼ in gas pipe to which the panels are attached by yokes and "U" bolts Fig 29 illustrates typical fittings

The merit of this type of framework is that no drilling is required, as fittings for carrying panels, transformers, etc , merely slide into the required position and are then tightened up

Angle-iron framework is also widely used, its supporters claiming that no special fitments are necessary, and it is therefore capable of more universal application

The cost of the two types of framework is approximately the same

For certain classes of duty it is sometimes desirable

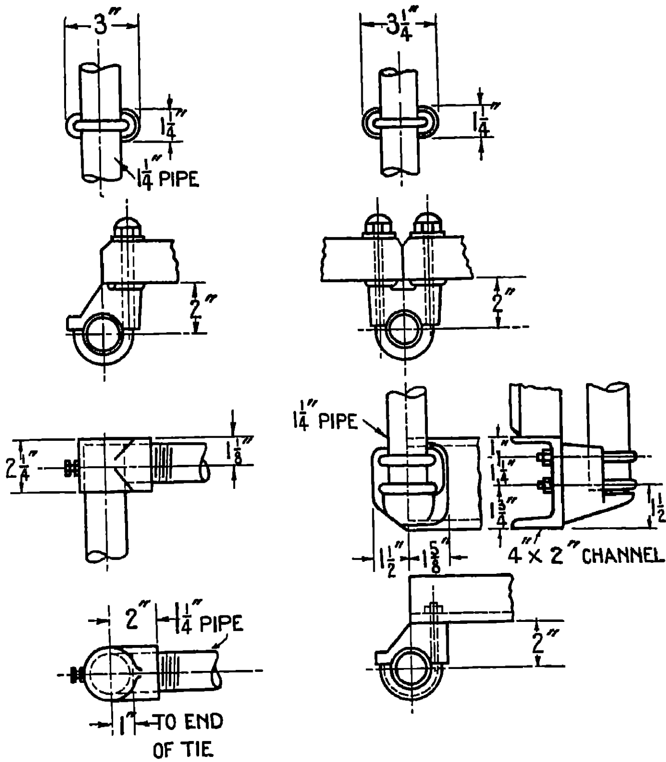


FIG 29 TYPICAL PIPE FRAMEWORK PANEL SUPPORTS

to insulate the framework from the switchboard panel In such cases, the fixing bolts have an insulating sleeve, with insulating washer back and front of the panel,

and the head of the bolt is enclosed in a moulded ebonite cap

Layout. While the disposition of apparatus on a switchboard panel is to some extent a matter of convention, such convention has a sound engineering basis

For example, on direct current switchboards it is customary to mount air circuit breakers high up on the panel, the reason being to allow the arc, which occurs when opening, to disperse above the panel

Similarly, lever switches are mounted with their handles at waist level, where they may be closed or opened with the maximum of convenience and safety to the operator

Meters, again, are placed wherever possible at eye level, where they may be easily read

In the case of alternating current switchboards the oil circuit breakers are mounted at the back of the panel, but the operating handle at the front is placed at a convenient level for closing

In the same way that apparatus is placed in orthodox positions, so it is common practice to place the busbars at the top of the switchboard where they are out of reach, and may be screened when work has to be carried out at the back of the panel

This position of the busbars also permits the simplest arrangement of interconnections, and thus effects economy in the amount of connection copper required

In the case of lighting and traction direct current switchboards, however, it is usually impracticable to place the busbars at the top of the panel, as two sets of busbars, together with an equalizer and neutral busbar, are required

To allow a convenient arrangement of the connections particularly on heavy current circuits, the bars on such boards must be placed at the level of the lever switches, barriers being fitted between the busbars with

in expanded metal enclosure to protect the bars against accidental contact

Busbars. The general requirements in respect to both direct current and alternating current busbars are set out in British Standard Specification No 1591, 925

Busbars may be constructed of either copper or aluminium strips, the former being more usual, due to the special precautions which must be taken to ensure permanently good contact at joints with aluminium

Up to 4000 amp direct current, and 2500 amp. 50 cycle, alternating current, $\frac{1}{4}$ in thick strips, spaced $\frac{1}{4}$ in apart, may be run at a density of 1000 amp per square inch without exceeding the permissible temperature rise of 30° C /35° C

Above these currents it is necessary to reduce the current densities , first, in the case of direct current, because the radiation surface does not increase in the same ratio as the cross-section, and, secondly, in the case of alternating current, because skin effect crowds the current into the outer strips and the inner strips do not carry their share of the current

The following tables show recommended busbar sections for direct current and alternating current on the basis of 30° C /35° C temperature rise

While it is standard practice to run copper busbars at 1000 amp per square inch, investigation shows that on industrial plants working eight hours or more per day, and at substantially full load, it pays to run at 800 amp per square inch density, as the saving in losses more than pays for the extra material

To ensure adequate ventilation the multiple strips forming a busbar are usually spaced from one another the thickness of the strip, and the strips bolted or clamped together at intervals to obtain equalization of current density

In the case of very heavy current alternating current

CAPACITY OF COPPER BUSBARS

DIRECT CURRENT, ¼ IN STRIP

Maximum Density 1000 amp per square inch

No of strips	Strips 4 × ¼ in		Strips 5 × ¼ in		Strips 6 × ¼ in	
	Amperes	Density	Amperes	Density	Amperes	Density
3	3000	1000	3700	990	4350	970
4	4000	1000	4700	940	5350	890
5	4950	990	5550	905	6400	855
6	5790	965	6650	890	7500	835
7	6650	950	7650	870	8450	805
8	7550	945	8550	855	9500	790

ALTERNATING CURRENT, 25 CYCLES, ¼ IN STRIP

Maximum Density 1000 amp per square inch

No of Strips	Strips 4 × ¼ in		Strips 5 × ¼ in		Strips 6 × ¼ in		Strips 8 × ¼ in		Strips 10 × ¼ in.	
	Amperes	Density	Amperes	Density	Amperes	Density	Amperes	Density	Amperes	Density
2	2000	1000	2500	1000	3000	1000	3860	965	4600	920
3	3000	1000	3650	970	4180	930	5110	850	6040	805
4	3850	960	4550	910	5200	870	6320	790	7350	735
5	4700	940	5300	850	6000	800	7250	725	8360	670
6	5150	860	5800	775	6500	720	7720	650	8740	585

Alternating Current, 50 Cycles, $\frac{1}{4}$ in Strip
Maximum Density 1000 amp per square inch

No of Strips	Strips 4 × $\frac{1}{4}$ in		Strips 5 × $\frac{1}{4}$ in		Strips 6 × $\frac{1}{4}$ in		Strips 8 × $\frac{1}{4}$ in.		Strips 10 × $\frac{1}{4}$ in	
	Amperes	Density	Amperes	Density	Amperes	Density	Amperes	Density	Amperes	Density
1	1000	1000	1250	1000	1500	1000	2000	1000	2500	1000
2	2000	1000	2500	1000	3000	1000	3750	940	4450	890
3	2900	960	3450	920	4000	890	4850	810	5700	760
4	3400	850	4150	830	4700	785	5700	715	6550	655

CAPACITY OF COPPER ROD
Freely Exposed Horizontally Mounted

For Rods in Vertical Position take 15 per cent less Current

Diameter	Maximum density for 30° C rise						Maximum density 1000 amp per square inch		
	D C	Density	25 cycles	Density	50 cycles	Density	D C	25 cycles	50 cycles
in									
$\frac{1}{2}$	350	1780	350	1780	350	1780	196	196	196
$\frac{5}{8}$	475	1550	475	1550	475	1550	307	307	307
$\frac{3}{4}$	620	1400	620	1400	615	1390	442	442	442
$\frac{7}{8}$	750	1250	750	1250	735	1220	601	601	601
1	880	1120	875	1110	850	1080	785	785	785
$1\frac{1}{4}$	1210	990	1190	970	1120	920	1210	1190	1120
$1\frac{1}{2}$	1570	870	1500	850	1380	790	1570	1500	1380
$1\frac{3}{4}$	1930	805	1780	740	1600	670	1930	1780	1600
2	2320	740	2080	660			2320	2080	
$2\frac{1}{2}$	3160	645					3160		

For purposes of reference the following tables show the corresponding capacities for aluminium conductors Maximum Density 600 amp per square inch

CAPACITY OF ALUMINIUM BUSBARS

DIRECT CURRENT, ¼ IN

No of Strips	Strips 4 × ¼ in		Strips 5 × ¼ in		Strips 6 × ¼ in	
	Amperes	Density	Amperes	Density	Amperes	Density
3	1800	600	2250	600	2700	600
4	2400	600	3000	600	3600	600
5	3000	600	3750	600	4500	600
6	3600	600	4500	600	5400	600
7	4200	600	5250	600	6300	600
8	4800	600	6000	600	7050	585

CAPACITY OF ALUMINIUM BUSBARS

ALTERNATING CURRENT, 25 CYCLES, ¼ IN

No of Strips	Strips 4 × ¼ in		Strips 5 × ¼ in		Strips 6 × ¼ in	
	Amperes	Density	Amperes	Density	Amperes	Density
3	1800	600	2250	600	2700	600
4	2400	600	3000	600	3600	600
5	3000	600	3750	600	4500	600
6	3600	600	4500	600	5350	590
7	4200	600	5250	600	5850	485
8	4800	600	5550	555	6150	455
9	5100	565	5650	500	6250	415

ALTERNATING CURRENT, 50 CYCLES, $\frac{1}{4}$ IN

Maximum Density 600 amp per square inch

	Strips 4 × $\frac{1}{4}$ in		Strips 5 × $\frac{1}{4}$ in		Strips 6 × $\frac{1}{4}$ in		Strips 8 × $\frac{1}{4}$ in		Strips 10 × $\frac{1}{4}$ in	
No of Strips	Amperes	Density	Amperes	Density	Amperes	Density	Amperes	Density	Amperes	Density
2	1200	600	1500	600	1800	600	2400	600	3000	600
3	1800	600	2250	600	2700	600	3600	600	4500	600
4	2400	600	3000	600	3600	600	4700	585	5450	545
5	3000	600	3750	600	4400	590	5250	525	6050	485
6	3600	600	4150	555	4700	520	5650	470	6350	425

CAPACITY OF ALUMINIUM ROD

FREELY EXPOSED HORIZONTALLY MOUNTED

For Rods in Vertical Position take 15 per cent less Current

Diameter in in	Maximum density for 30° C rise						Maximum density 600 amp per square inch		
	D C	Density	25 cycles	Density	50 cycles	Density	D C	25 cycles	50 cycles
$\frac{1}{2}$	242	1230	242	1230	242	1230	118	118	118
$\frac{5}{8}$	330	1080	330	1080	330	1080	184	184	184
$\frac{3}{4}$	430	975	430	975	430	975	265	265	265
$\frac{7}{8}$	520	865	520	865	518	860	361	361	361
1	610	778	610	778	600	765	471	471	471
$1\frac{1}{4}$	840	661	836	658	810	638	762	762	762
$1\frac{1}{2}$	1090	1070	607	1020	578	578	1060	1062	1020
$1\frac{3}{4}$	1340	558	1300	542	1215	506	1340	1300	1215
2	1610	513	1530	488	1390	443	1610	1530	1390
$2\frac{1}{2}$	2190	446	1980	403	1730	353	2190	1980	1730

busbars, skin effect plays a very prominent part in the current carrying capacity, so much so that above certain sections it is impracticable to increase the

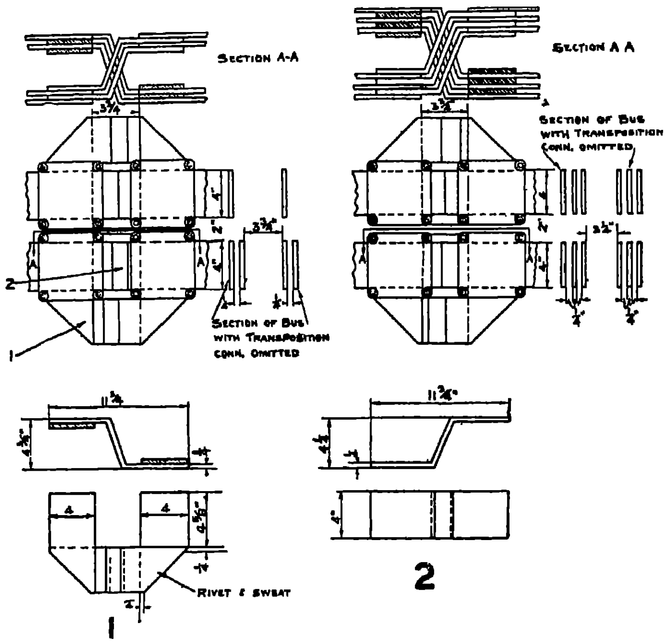


FIG 30 TRANSPOSITION CONNECTIONS FOR HEAVY ALTERNATING CURRENT BUSBARS

capacities by adding additional strips For this reason it is necessary to employ a special construction to overcome skin effect by crossing over the inner and outer conductors in the busbar at one or more points, the strips being lightly insulated from one another, except at one point only, where they are paralleled to equalize the load

Fig 30 illustrates typical transposition connections

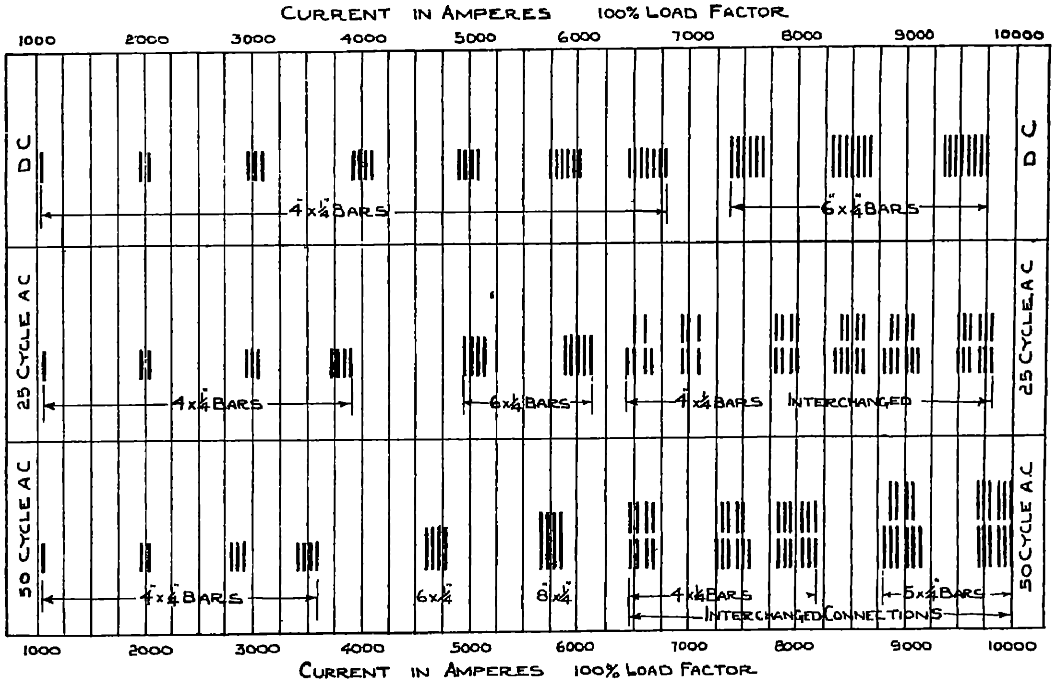


FIG 31. SECTIONS OF ALTERNATING CURRENT AND DIRECT CURRENT BUSBARS 30–35° C TEMP RISE

for currents above 6000 amp alternating current, and Fig 31 shows graphically the cross-section of busbars recommended for currents up to 10,000 amp alternating current and direct current

Expansion of Busbars. The coefficient of expansion of copper is 0000166 per degree Centigrade, so that on a switchboard say 50 ft long, the bars will extend 32 for a 30° C rise, or, allowing a variation between summer and winter temperature of 35° C, the total alteration in length will be 7 in

While well-designed busbar supports are arranged to allow the busbars to slide horizontally, this does not take care of the branch connections, which may be short, stiff connections to circuit breaker or switch terminal studs Any movement of these connections would impose heavy stresses on the apparatus, so that expansion joints in the busbars are essential

Fig 32 illustrates a typical expansion joint constructed of ·01 thick copper strip for use where the space available is limited

	Maximum lengths of busbars				
	ft 6	ft 9	ft 12	ft 18	ft 24
A	in 5	in 6	in $6\frac{1}{2}$	in 8	in 9
B	in $1\frac{1}{8}$	in $1\frac{3}{8}$	in $1\frac{9}{16}$	in $1\frac{7}{8}$	in $2\frac{1}{4}$
C	in $\frac{1}{4}$	in $\frac{1}{4}$	in $\frac{1}{4}$	in $\frac{1}{4}$	in $\frac{1}{4}$
D	in $1\frac{3}{8}$	in $1\frac{5}{8}$	in $1\frac{13}{16}$	in $2\frac{1}{8}$	in $2\frac{1}{2}$
E	in $2\frac{1}{2}$	in 3	in $3\frac{1}{4}$	in 4	in $4\frac{1}{2}$

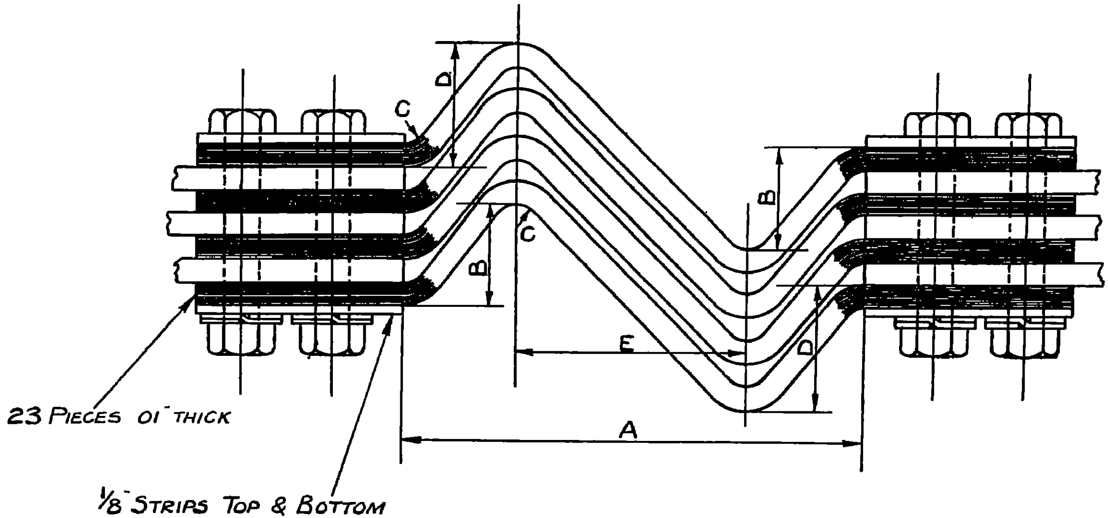


FIG 32 BUSBAR EXPANSION JOINT

Joints of this type are employed every 12 ft to 25 ft, according to the section of the busbars and the arrangement of the branch connections

Copper Connections. The cross-sectional area of copper or aluminium connections is chosen on the same basis as for busbars, except that the temperature rise in long vertical connections is greater than with the strips mounted horizontally, due to the reduced radiation

Joints between busbars and branch connections are

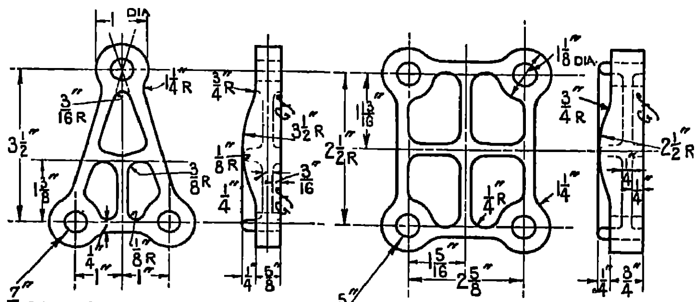


Fig 33 Busbar Clamps

made with clamps in preference to bolts, in that the former allow the busbar strips to slide and so prevent stresses on the connections due to expansion

Fig 33 illustrates typical busbar clamps which are fixed with steel bolts for direct current work, but brass or gunmetal studs for alternating current work

Where clamps are not permissible for joints in connections, bolts are used, the size and spacing of the bolts being in accordance with Fig 34

Tests confirmed by experience show that to secure good and permanent contact it is necessary to have ample contact pressure between surfaces For this reason clamps are more satisfactory, but reliable contact between bolted surfaces is obtained by tinning the

STANDARD BOLTING FOR BUSBARS AND CONNECTION BARS

ALL JOINTS TO BE TINNED

Bars A	Bars B	Fig	C	D	E	F	G	Bolt	Bars A	Bars B	Fig	C	D	E	F	G	Bolt	Bars A	Bars B	Fig	C	D	E	F	G	Bolt
In	In		In	In	In	In	In		In	In		In	In	In	In	In	In	In	In		In	In	In	In	In	In
½	½	1	¼				½	OBA	3	1	2	⅝	1¾			17/32	½	7	2½	2	1¼	4½			21/32	⅝
⅝	½	1	5/16				½	OBA	3	1¼	2	⅝	1¾			17/32	½	7	3	4	1¼	4½	¾	1½	21/32	⅝
⅝	⅝	1	5/16				½	OBA	3	1½	2	⅝	1¾			17/32	½	7	4	4	1¼	4½	1	2	21/32	⅝
¾	½	1	⅜				½	OBA	3	2	4	⅝	1¾	½	1	13/32	⅜	7	5	5	1¼	2¼	1¼	2¼	21/32	⅝
¾	¾	1	⅜				½	OBA										7	6	6	1¼	2¼	1	2	21/32	⅝
¾	¾	1	⅜				½	OBA	3	2½	4	⅝	1¾	⅝	1¼	17/32	½	7	7	6	1¼	2¼	1¼	2¼	21/32	⅝†
1	¾	1	½				13/32	⅜ in										8	3	4	1½	5	¾	1½	21/32	⅝
1	1	1	½				13/32	⅜ in	3	3	4	⅝	1¾	⅝	1¾	17/32	½*	8	4	4	1½	5	1	2	21/32	⅝
1¼	¾	1	5/16	⅝			½	OBA										8	5	5	1½	2¾	1¼	2½	21/32	⅝
1¼	1	2	5/16	⅝			½	OBA	4	1¼	2	⅞	2¼			17/32	½	8	6	6	1½	2¾	1	2	21/32	⅝
1¼	1¼	1	⅝				17/32	½ in	4	1½	2	⅞	2¼			17/32	½	8	7	6	1½	2¾	1	2½	21/32	⅝
1½	¾	2	5/16	⅞			½	OBA	4	2	2	⅞	2¼			21/32	⅝	8	8	6	1½	2¾	1¼	2¾	21/32	⅝†
1½	1	1	¾				17/32	½ in	4	2½	4	⅞	2¼	⅝	1¼	17/32	½	10	4	5	1½	3¾	1	2	21/32	⅝
1½	1¼	1	¾				17/32	½ in	4	3	4	⅞	2¼	⅝	1¾	17/32	½	10	5	5	1½	3¾	1	3	21/32	⅝
1½	1½	1	¾				17/32	½ in										10	6	6	1½	3¾	1	2	21/32	⅝
1¾	¾	2	⅜	1			½	OBA	4	4	4	⅞	2¼	⅞	2¼	21/32	⅝†	10	7	6	1½	3¾	1	2½	21/32	⅝
1¾	1	2	⅜	1			13/32	⅜ in										10	8	6	1½	3¾	1¼	2¾	21/32	⅝
1¾	1¼	2	⅜	1			13/32	⅜ in	5	1	2	¾	3½			17/32	½									
2	¾	2	½	1			13/32	⅜ in	5	1¼	2	¾	3½			17/32	½									
2	1	2	½	1			13/32	⅜ in	5	1½	2	¾	3½			17/32	½									
2	1¼	1	½	1			13/32	⅜ in	5	2	2	¾	3½			17/32	½									
2	1½	2	½	1			13/32	⅜ in	5	2½	3	¾	1¾			17/32	½									
									5	3	4	1¼	2½	¾	1½	21/32	⅝									
2	2	4	½	1	½	1	13/32	⅜ in	5	4	4	1¼	2½	⅞	2¼	21/32	⅝									
									5	5	5	1	1½	1¼	2½	21/32	⅝†									
2½	1	2	⅝	1¼			13/32	⅜ in	6	2	2	1	4			17/32	½									
2½	1¼	2	⅝	1¼			13/32	⅜ in	6	2½	3	1	2			17/32	½									
2½	1½	2	⅝	1¼			17/32	½ in	6	3	4	1	4	¾	1½	21/32	⅝									
2½	2	4	⅝	1¼	½	1	13/32	⅜ in	6	4	4	1	4	1	2	21/32	⅝									
2½	2½	4	⅝	1¼	⅝	1¼	13/32	⅜ in	6	5	5	1	2	1¼	2½	21/32	⅝									
									6	6	6	1	2	1	2	21/32	⅝†									

* Not to be used if the total thickness of busbar exceeds 1¾ in (4 bars, 3 spaces)
† Not to be used if the total thickness of busbar exceeds 2¾ in (6 bars, 5 spaces)
Hexagon head bolts to be used for all joints

contact surfaces or inserting a layer of tinfoil between the surfaces

Position and Colouring of Busbars and Connections. The relative position of the positive and negative busbars and connections on a direct current switchboard, and also that on the phases of an alternating current switchboard, follow the conventions laid down in British Standard Specification No 158

This specification also sets out the colouring which

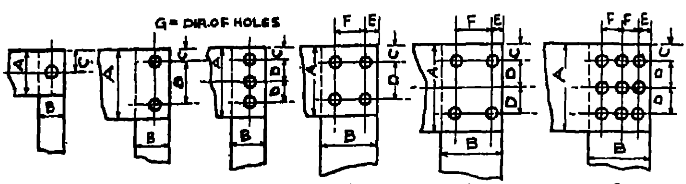


FIG 34 BOLTING DETAILS FOR BUSBAR AND CONNECTION JOINTS

should be applied to the poles and phases, such colourings usually being applied in anti-sulphuric enamel

GENERAL ARRANGEMENT OF DIRECT CURRENT AND LOW TENSION ALTERNATING CURRENT SWITCHBOARDS

STANDARD SPECIFICATIONS AND REGULATIONS

The general requirements as applying to direct current and low tension alternating current switchboards are set out in Parts I and II of British Standard Specification No 162, 1928 In addition, all switchboards must conform to the Factory Acts and Regulations, or to the Coal Mines Regulations Act, according to the duty and location of the board These Acts stipulate the minimum gangways and head-room permitted, the requirements in regard to earthing as laid down, and many other important conditions specified,

which must be met before a switchboard can be passed for service by the authority concerned

Front of Panel Finish. Switchboards may be finished on the front in black and copper, black and nickel, or bright and dull black The latter is considered the most serviceable, as plated finishes become corroded in course of time

Rating. Switchboards are maximum rated, that is to say, the current rating is the maximum continuous current they will carry with a temperature rise not exceeding 30° C or 40° C , as the case may be This is important, as although the " maximum continuous rating " of electrical plant is becoming more widely used, some purchasers still specify that the circuit rating is subject to 25 per cent overload, and in the case of alternating current circuits a particular power factor is specified.

Instrument Equipment. Instruments and meters as such are dealt with separately in this publication, so that reference is made here only to their application

Ammeters are fitted to most circuits, one being sufficient on a 2-wire direct current circuit, two being required on a 3-wire direct current circuit, and one with or without an ammeter switch for three-phase alternating circuits

Direct current moving coil ammeters above 100 amp usually have external shunts, which in the case of heavy currents, say 5000 amp and above, should be mounted horizontally to obtain proper radiation of the heat generated

Alternating current ammeters of the moving iron type may be obtained of the series type, but it is usually more convenient to employ 5 amp windings operated from current transformers

Voltmeters are usually mounted on a swing bracket at the end of a switchboard, and connected to the

busbars Where it is desired to read the pressure between poles and neutral, or phases to neutral, a voltmeter switch is employed

Power Factor Meters are fitted to alternating current generators, synchronous motors, and rotary convertor panels

Indicating Wattmeters are fitted to alternating current generator panels

Integrating Watthour Meters are fitted to all classes of alternating current and direct current panels, where it is required to register the input or output of the circuit

Earth Detectors may be employed on both direct current and alternating current circuits with either neutral insulated or earthed Such instruments give both an indication as to the condition of the system insulation, and also a definite reading when a line conductor is defective

Field Rheostats. On low tension switchboards it is usual to mount generator field rheostats at the back or at the top of the generator panel, and operate them from a handwheel at the front

Rheostats, when not direct operated, may be either chain or bevel operated The former is more usual, but necessitates chain guards to ensure that a broken chain does not fall across the busbars or connections

Where the generator is of a heavy current rating it is important that the rheostats are mounted so that they are adequately ventilated, as otherwise the combined heating of the switchboard materials and the rheostats results in temperature rises in both exceeding the permissible limits

In such cases it is often convenient to locate the rheostats in the basement, and operate them from a pedestal standing in front of the switchboard

Equipment of Direct Current Switchboards. Standard

equipment for direct current switchboards up to 660 volts is covered by British Standard Specification No 194, 1926

This sets out the minimum equipment recommended for the control of the following circuits—

Direct current feeders, 1, 2, and 3 wire
Direct current generators, 2 and 3 wire
Direct current rotary convertors, 2 and 3 wire

In general, the equipment listed in this specification should be regarded as the minimum for satisfactory operation, it being desirable in many cases to employ in addition the apparatus described as "optional extras"

While the standard equipments are laid down in British Standard Specification 194, the actual layout of the panels depends to some extent upon the practice of the manufacturers and the preference of the purchaser.

Typical assemblies are shown in Figs 35 to 39

Typical switchboards are illustrated in Figs 40 to 44

High Voltage Traction Switchboards. Where the bus-bar pressure exceeds 660 volts, such as on 800 volts or 1200 volts traction systems, it is necessary in the interests of safety to mechanically operate the circuit breakers and lever switches, the former being mounted above the panels and the latter behind the panels

Figs 45 and 46 illustrate switchboards of this type, which it will be seen are virtually dead front boards

For even higher pressure, such as 1500 volts or 3000 volts, high speed circuit breakers are employed, and in this case a similar construction is adopted, but the circuit breakers are supported by a gallery above the switchboard, in order to permit convenient access to the breakers for maintenance work This class of switchboard is described in detail in the "Automatic Sub-station" section of this series of books

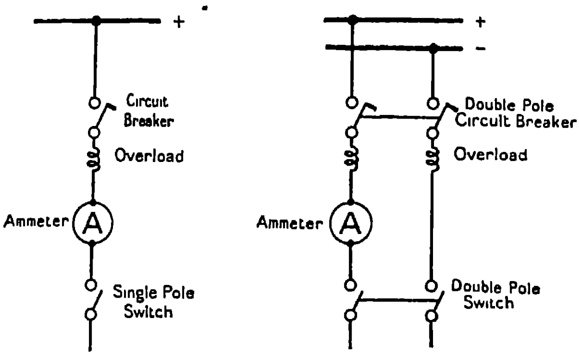


FIG 35

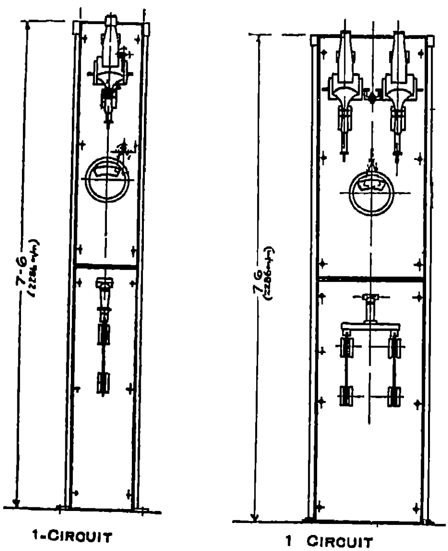


FIG 35A DIRECT CURRENT FEEDER PANELS

D C FEEDER EQUIPMENTS WITH CIRCUIT BREAKERS

Type	Type of circuit		Number of circuits	Rating amperes	Standard equipment for one circuit (see figures)	Optional extra equipment*
	Busbar	Distribution feeder				
I A	Single-wire	Single wire	1, 2, or 3	100, 150, 200, 300, 400, 500, 600, 800, 1000, 1200	1 single-pole circuit breaker with overload device 1 ammeter 1 single-pole, air-break, quick-break, single-throw switch	Watt-hour meters Wattmeters Voltmeters Special attachment to circuit breakers (see B S S No 110)
I B	Two-wire	Two wire	1, 2, 3 or 4	60, 100, 150, 200, 300, 400, 500, 600 (for 1 & 2 circuits, also 800, 1000, 1200)	1 double-pole circuit breaker with two overload devices 1 ammeter 1 double-pole air-break, quick break, single-throw switch	Do

D C FEEDER EQUIPMENTS WITH FUSES

Type	Type of circuit		Number of circuits	Rating amperes	Standard equipment for one circuit (see figures)	Optional extra equipment*
	Busbar	Distribution feeder				
II A	Single-wire	Single-wire	1, 2, or 3	100, 150, 200, 300	1 single-pole fuse 1 single-pole, single throw, lever switch 1 ammeter	
II B	Two-wire	Two-wire	1, 2 or 4 3 or 6	60, 100 150, 200, 300 60 only	2 single pole fuses 1 double pole, single-throw, lever switch 1 summation ammeter	1 ammeter per circuit for 1, 2, and 4 circuits only
II C	Three-wire	Two-wire	1, 2, 4 3 or 6	Do	Do	Do

* Switchboards intended for service which does not permit of complete shutting down so that all conductors can be made wholly dead when necessary for cleaning, examination, adjustment or repair of working parts requiring frequent attention (such as those of circuit-breakers), shall be provided with means so that portions containing such parts may individually be made dead and in order to prevent danger from live conductors on adjacent portions, permanent or removable screens shall be provided so that work on any dead portion may be carried on safely

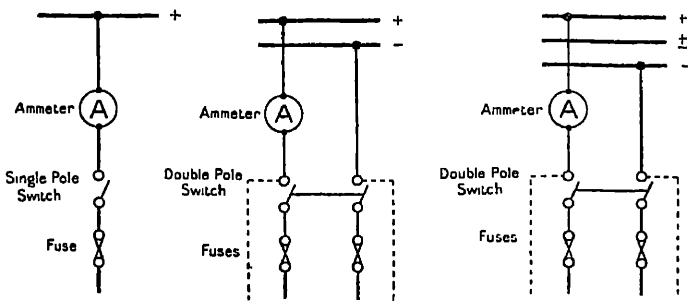


FIG 36

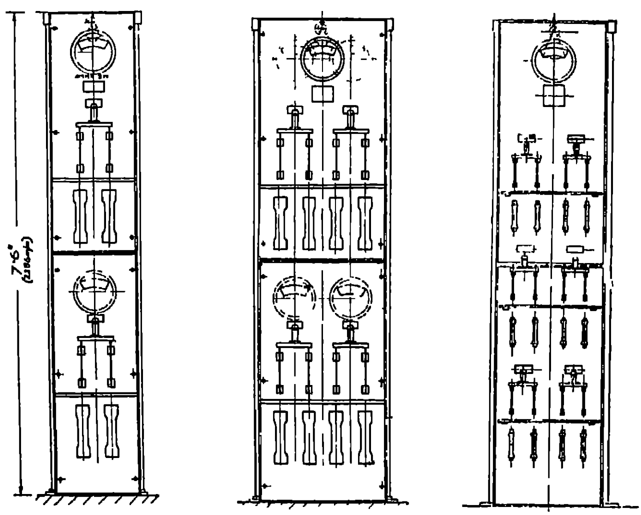


FIG 36A FUSE DISTRIBUTION PANELS

D C GENERATOR EQUIPMENTS

Type	Busbar	Generator	Distribution	Rating amperes	Standard equipment (see figure)	Optional extra equipment
III A	Two wire	Shunt	Two-wire	60, 100, 150, 200, 300, 400, 500, 600, 800, 1000, 1200, 1600, 2000, 2500, 3000, 3500, 4000	1 single-pole overload and reverse current circuit breaker 1 ammeter 2 single pole, single-throw, main switches *1 single-pole field discharge switch and resistance 2 potential fuses *1 field rheostat and operating device	1 two-wire watt-hour-meter 1 voltmeter 1 switch or plugging device for voltmeter
III B	Two wire	Shunt	Three wire	Do	1 single-pole overload and reverse-current circuit breaker 1 ammeter 2 single-pole, single-throw, main switches *1 single-pole field discharge switch and resistance 2 potential fuses *1 field rheostat and operating device	1 single-pole overload circuit breaker interlocked with the other circuit breaker, if it is desired to protect faults on machine 1 two-wire watt-hour meter †1 voltmeter †1 switch or plugging device for voltmeter
III G	Two-wire or Three wire	Compound or Shunt (with equalizer bar situated at switchboard)	Two-wire Traction or Three-wire Lighting	Do	2 interlocked single pole, overload and reverse-current circuit breakers, or 1 double-pole overload circuit breaker, fitted with reverse current device on each pole 2 ammeters 2 single-pole, double throw, main switches 1 single-pole, single throw, main switch 1 single pole, single-throw, neutral switch 1 single-pole field discharge switch and resistance 2 potential fuses 1 field rheostat and operating device	1 single-pole over load circuit breaker mounted near machine, if it is desired to protect faults on machine 1 mid-wire ammeter 2 two wire watt hour meters and fuses 1 voltmeter 1 switch or plugging device for voltmeter

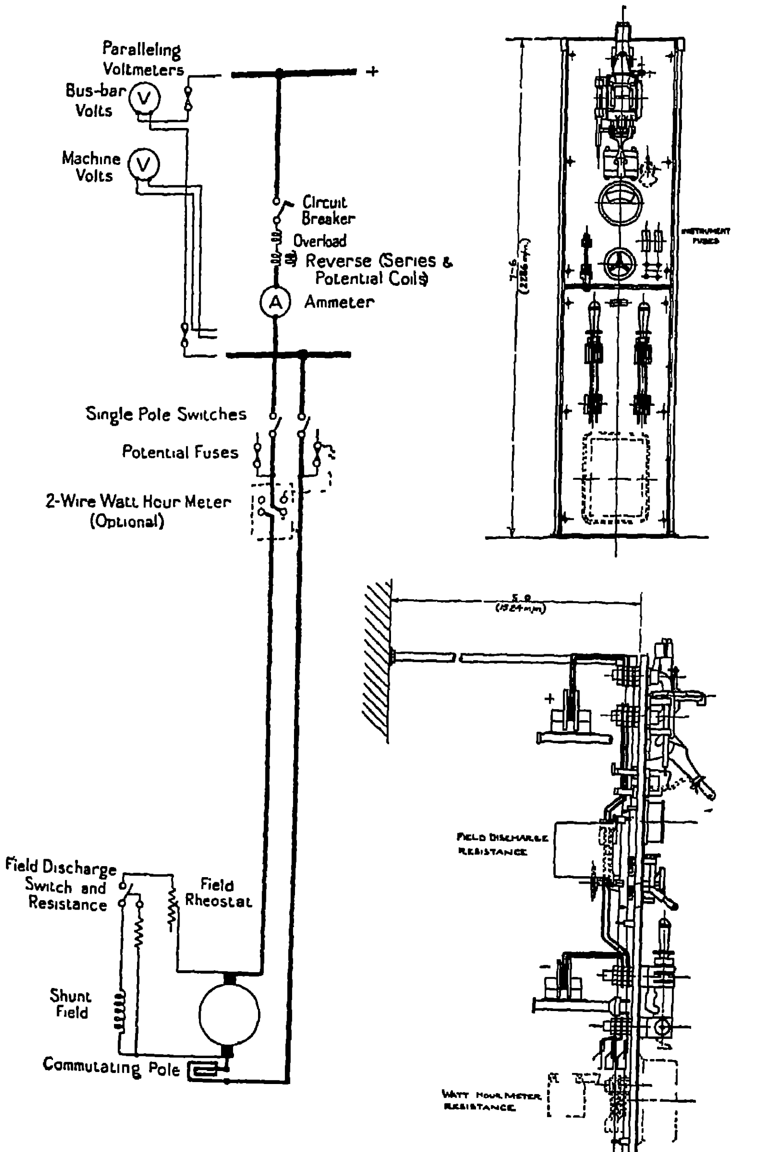


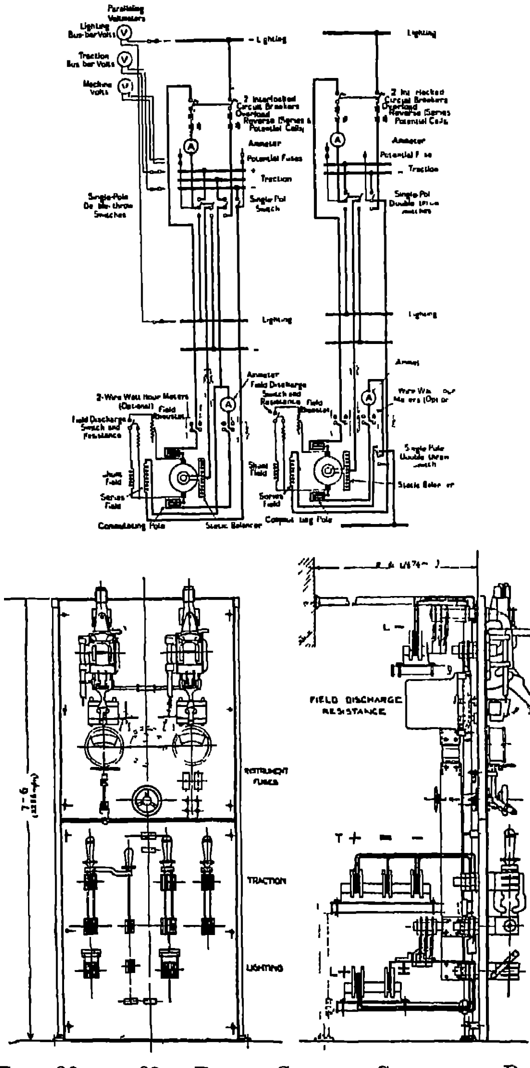
FIG 37 DIRECT CURRENT GENERATOR PANEL

D C GENERATOR EQUIPMENTS—*continued*

Type	Busbar	Generator	Distribution	Rating amperes	Standard equipment (see figures)	Optional extra equipment
HLH	Two-wire or Three-wire	Compound or Shunt (with equalizer bar situated at machine)	Two-wire Traction or Three wire Lighting	60, 100, 150, 200, 300, 400, 500, 600, 800, 1000, 1200, 1600 2000, 2500, 3000, 3500, 4000	2 interlocked single pole, overload and reverse-current circuit breakers, or 1 double-pole overload circuit breaker fitted with reverse-current device on each pole 2 ammeters 2 single pole, double throw, main switches 1 single pole, single throw, neutral switch 1 single pole field discharge switch and resistance 2 potential fuses 1 single pole, double throw main switch mounted near machine 1 field rheostat and operating device	1 single pole overload circuit breaker mounted near machine, if it is desired to protect faults on machine 1 mid-wire ammeter 2 two-wire watt-hour meters and fuses 1 voltmeter 1 switch or plugging device for voltmeter

* The field rheostat is usually provided as part of the generator contract and may be mounted on, or operated from, the control panel, or alternatively, provision may be made for pedestal operation, in which case the field switch may, if desired, be mounted on the pedestal

† Where two or more generators are arranged for parallel running, paralleling voltmeters must be provided together with the necessary switching or plugging devices, in which case it is usual to mount the voltmeters on a separate panel, the switch or plugging devices being mounted on the generator panels

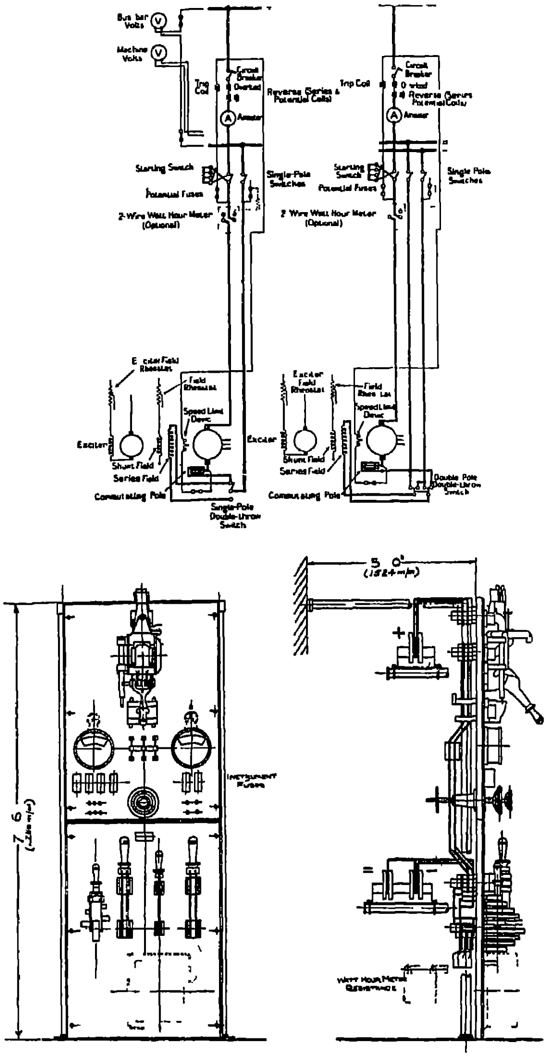


FIGS 38 AND 38A DIRECT CURRENT GENERATOR PANEL

Type	Busbar	Rotary Convertor	Distribution	Rating amperes	Standard equipment (see figures)	Optional extra equipment
IV E	Two wire Two-wire	Shunt (A C to D C) Compound (A C to D C or D C to A C) (Not suitable for inverted running when compounded)	Two-wire	60, 100, 150, 200, 300, 400, 500, 600, 800, 1000, 1200, 1600, 2000, 2500, 3000, 3500, 4000	1 single-pole overload and reverse-current circuit breaker 1 ammeter 2 single-pole, single-throw, main switches 2 potential fuses 1 starting switch *1 single-pole, single-throw starter short-circuiting switch. 1 single-pole, double throw, change-over switch for opening and closing series winding 1 trip coil for operation from speed limiting device or other safety device 1 field rheostat and operating device	1 two-wire watt-hour meter 1 voltmeter 1 switch or plugging device for voltmeter 1 exciter voltmeter 1 switch or plugging device for exciter paralleling 1 triple-pole, double throw, make-before break change-over switch for exciter paralleling 4 instrument fuses for exciter paralleling voltmeter 1 exciter field rheostat and operating device
IV F	Two wire Two-wire	Compound (A C to D C) Compound (A C to D C and D C to A C)	Three-wire	Do	1 single-pole overload and reverse current circuit breaker 1 ammeter 2 single-pole, single-throw, main switches 1 single-pole, single-throw equalizer switch 2 potential fuses 1 starting switch *1 single-pole, single-throw starter short-circuiting switch. 1 double-pole, double throw, reversing switch, for series winding 1 trip coil for operation from speed limiting device, or other safety device 1 field rheostat and operating device	1 two-wire watt hour meter 1 voltmeter 1 switch or plugging device for voltmeter 1 exciter voltmeter 1 switch or plugging device for exciter paralleling 1 triple-pole, double-throw, make-before-break change-over switch for exciter paralleling 4 instrument fuses for exciter paralleling voltmeter 1 exciter field rheostat and operating device

* Where the capacity of the starting switch is suitable for carrying full load currents continuously, short-circuiting switch is not required

NOTE The foregoing data on Feeder, Generator, and Rotary Convertor Equipments have been reproduced by permission of the British Engineering Standards Association from its specification No 194, 1926, copies of which can be obtained from the office of the Association, 28 Victoria Street, London, S W 1 Price, 1s 2d post free



FIGS 39 AND 39A DIRECT CURRENT ROTARY CONVERTOR PANEL

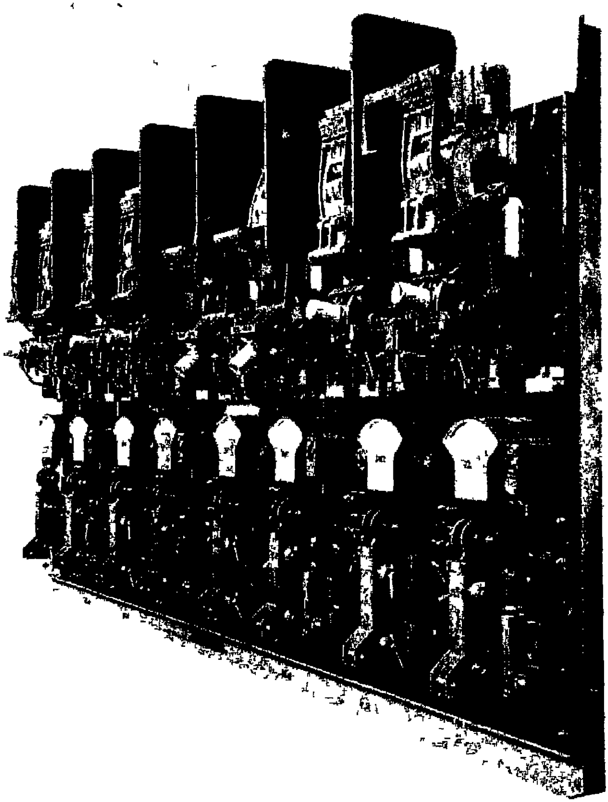


FIG 40 FRONT VIEW OF HEAVY CURRENT DIRECT CURRENT SWITCHBOARD

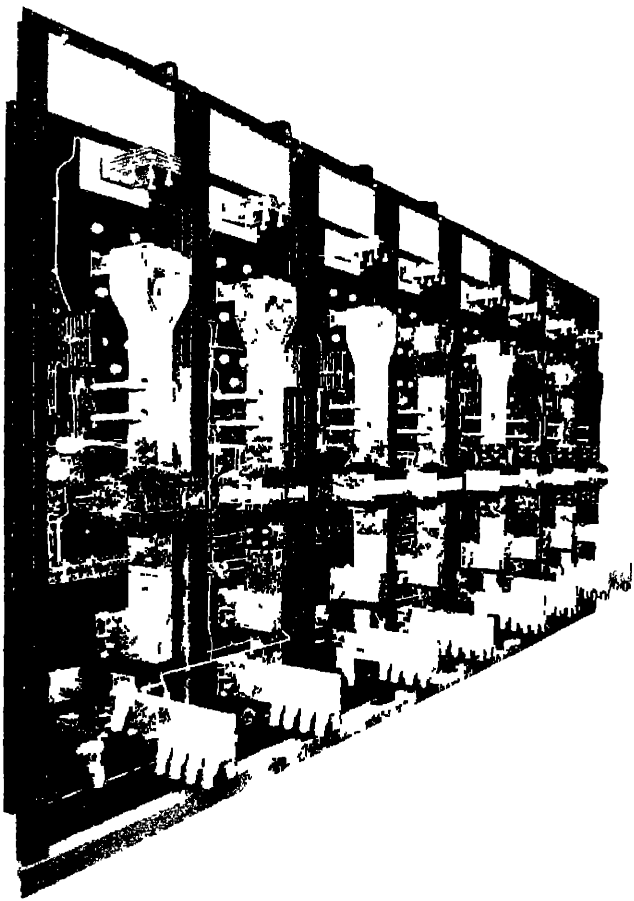


FIG 41 BACK VIEW OF HEAVY CURRENT DIRECT CURRENT SWITCHBOARD

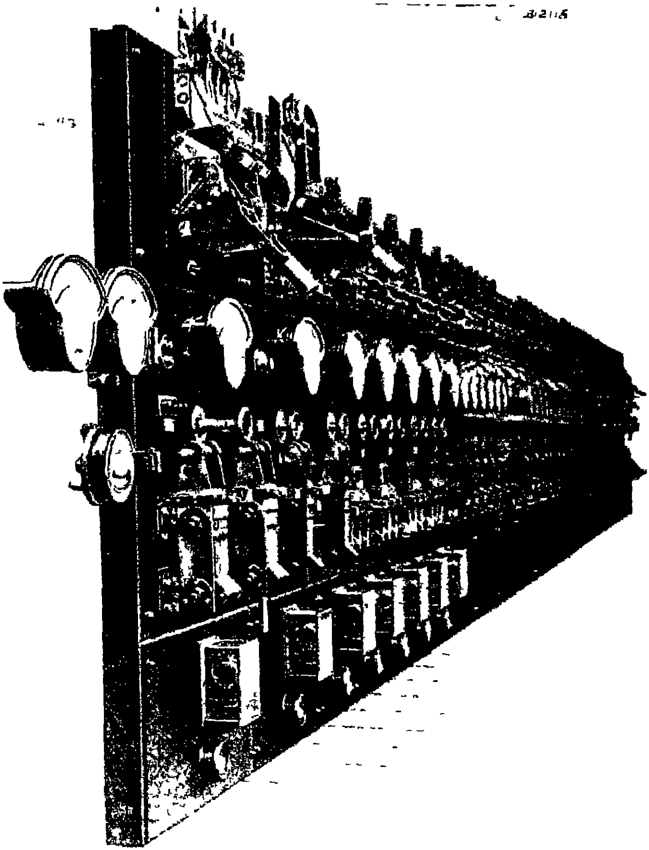


FIG 42 FRONT VIEW OF 500 VOLTS DIRECT CURRENT POWER SWITCHBOARD

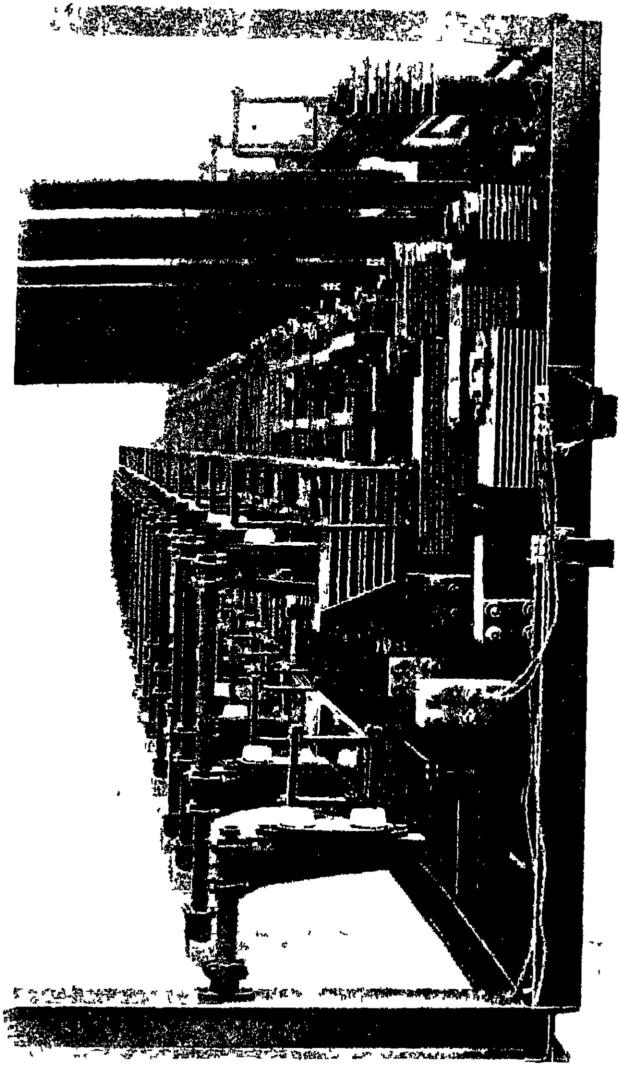


FIG 43 SIDE VIEW OF 500 VOLTS DIRECT CURRENT POWER SWITCHBOARD

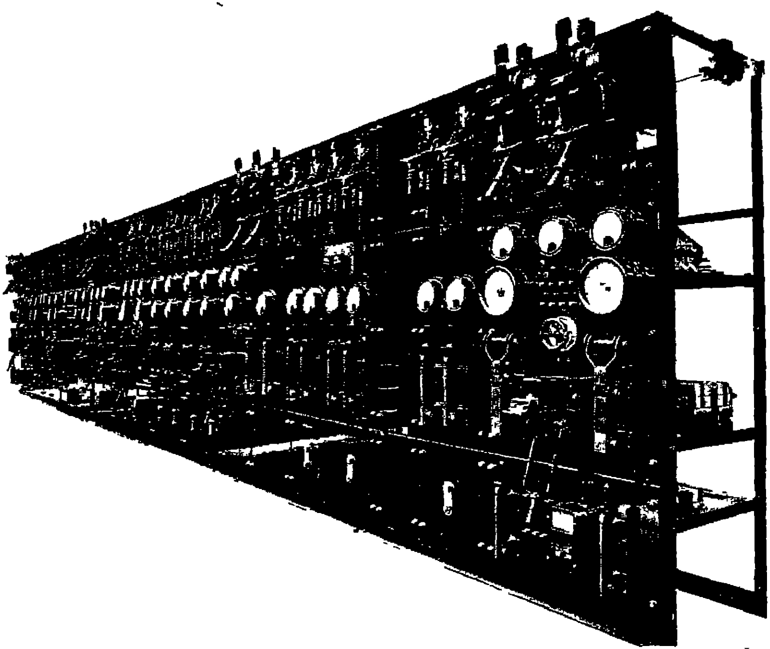


FIG 44 FRONT VIEW OF DIRECT CURRENT SWITCHBOARD

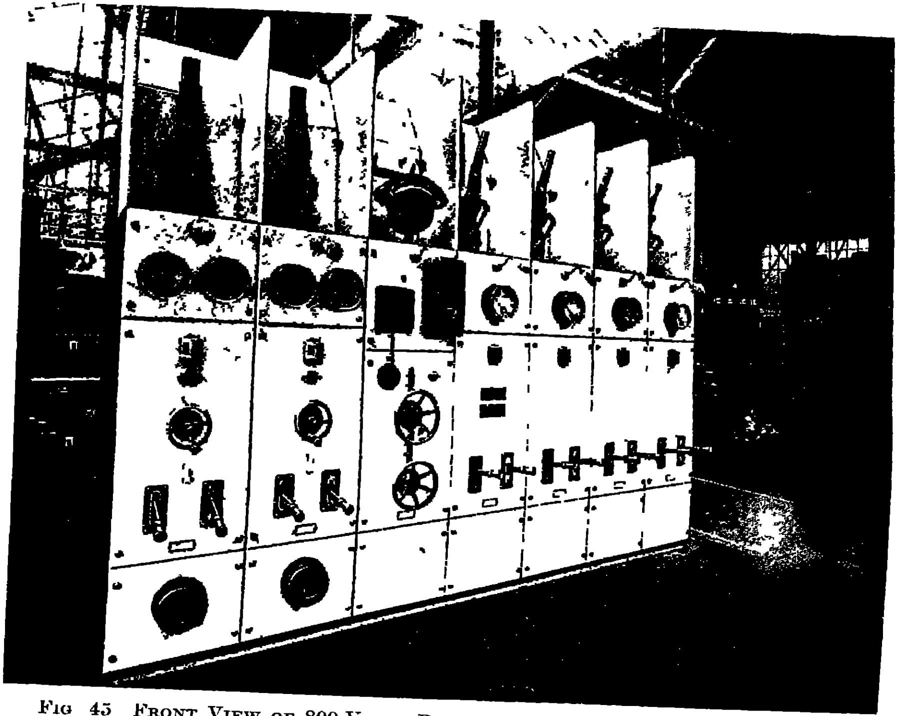


FIG 45 FRONT VIEW OF 800 VOLTS DIRECT CURRENT TRACTION SWITCHBOARD

FIG. 46. BACK VIEW OF 800 VOLTS DIRECT CURRENT TRACTION SWITCHBOARD

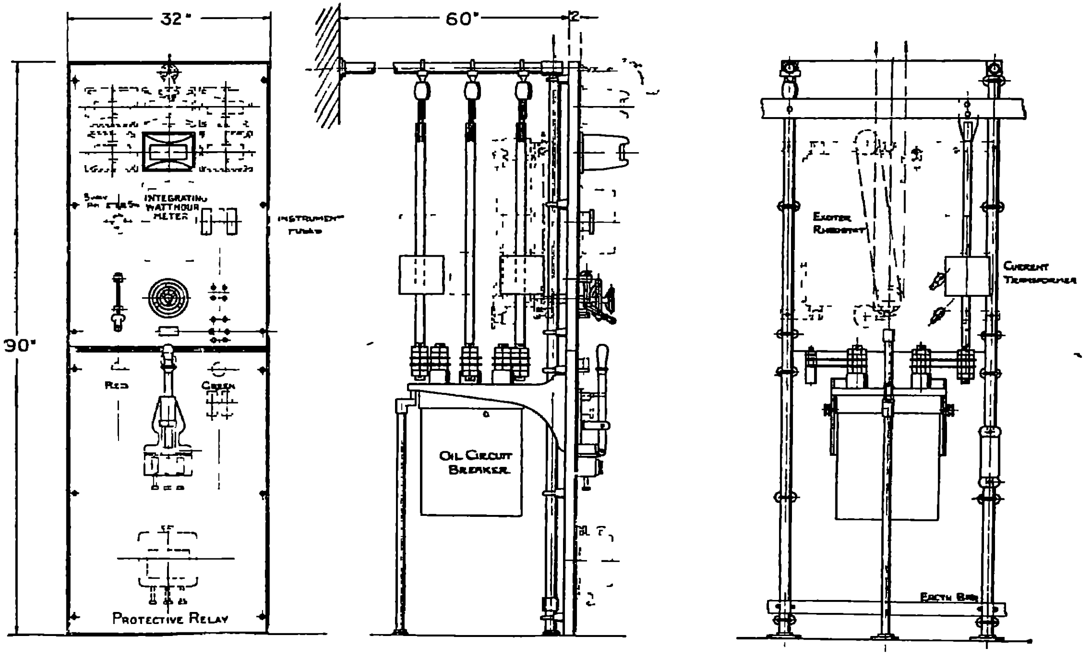


FIG 47 LOW TENSION ALTERNATING CURRENT GENERATOR PANEL

Equipment of Alternating Current Switchboards. The British Engineering Standards Association is engaged upon a specification covering standard equipment for alternating current switchboards which will be issued as B S S 195, 1929

This will set out the minimum equipments recommended for the control of the following circuit—

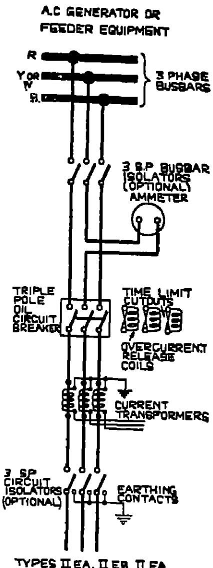


FIG 47A

- Alternating current feeders
- Alternating current generators
- Alternating current motor convertors
- Alternating current rotary convertors
- Alternating current *la Cour* convertors
- Synchronizing equipments

The equipment to be listed will be the minimum recommended for satisfactory working, but in many cases it will be desirable to employ the apparatus detailed as "optional extras"

The layout of the alternating current panels depends to an even greater extent than direct current panels upon the practice of the manufacturers, the requirements of the purchaser, and the duty of the switchboard

Typical panels are shown in Figs 47 and 48

For certain classes of service, where it is either impracticable or inconvenient to shut down a switchboard for maintenance or cleaning, it is customary to fit isolating switches between the busbars and the oil circuit breaker In addition, sheet iron partitions may

Type	Standard equipment	Optional extra equipment
II EA Fig 47	1 ammeter 1 voltmeter 1 triple-pole, oil-immersed circuit breaker 3 overload current releases, and/or other protective gear 3 current transformers 1 hand operating device for oil-immersed circuit breaker 1 double-pole, single-throw, field discharge switch and resistor 1 field rheostat and operating device NOTE This rheostat may be for the alternator or exciter field, or one rheostat for each may be provided	2 extra ammeters 1 indicating wattmeter 1 watt-hour meter 1 power factor meter 1 frequency meter 1 exciter ammeter 1 exciter voltmeter 1 three-way ammeter switch (where transformer operated meters are employed) 1 set of instrument cutouts 3 time-limit devices for over current releases 1 under-voltage release 1 earth-leakage release device NOTE Two over current releases only are necessary when an earth leakage release device is included 1 set of synchronizing equipment (see Section VII) 3 busbar isolators for pole operation 3 circuit isolators for pole operation (with or without earthing contacts) Safety catches for isolators 1 operating pole for isolators 1 switch or plugging device for voltmeter 1 switch or plugging device for exciter voltmeter 1 tank lifting and lowering device for oil-immersed circuit breaker First filling of oil for circuit breaker Cable box or boxes
II FA Fig 48	1 ammeter 1 triple-pole, oil-immersed circuit breaker, or 3 single pole, oil-immersed circuit breaker 3 over current releases, and/or other protective gear 3 current transformers	2 extra ammeters 1 voltmeter 1 indicating wattmeter 1 watt-hour meter 1 power factor meter 1 three-way ammeter switch, where transformer operated meters are employed 3 busbar isolators for pole operation 3 circuit isolators for pole operation (with or without earthing contacts) 3 time limit devices for over current releases 1 under-voltage release 1 earth leakage release device NOTE Two over current releases only are necessary when an earth leakage release device is included 1 set of instrument cutouts Charging resistances for oil-immersed circuit breaker First filling of oil for circuit breaker 1 operating pole for isolators, safety catches for isolators 1 tank lifting and lowering device for oil immersed circuit breakers Cable box or boxes

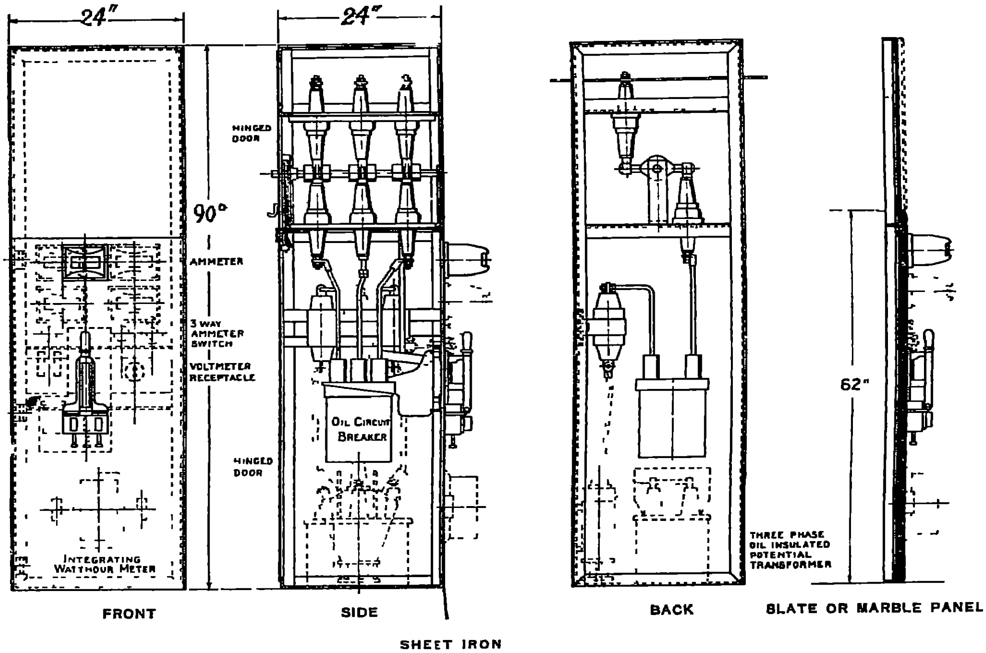


FIG 51 STEEL CUBICLE SWITCHING EQUIPMENT WITH INTERLOCKED ISOLATORS

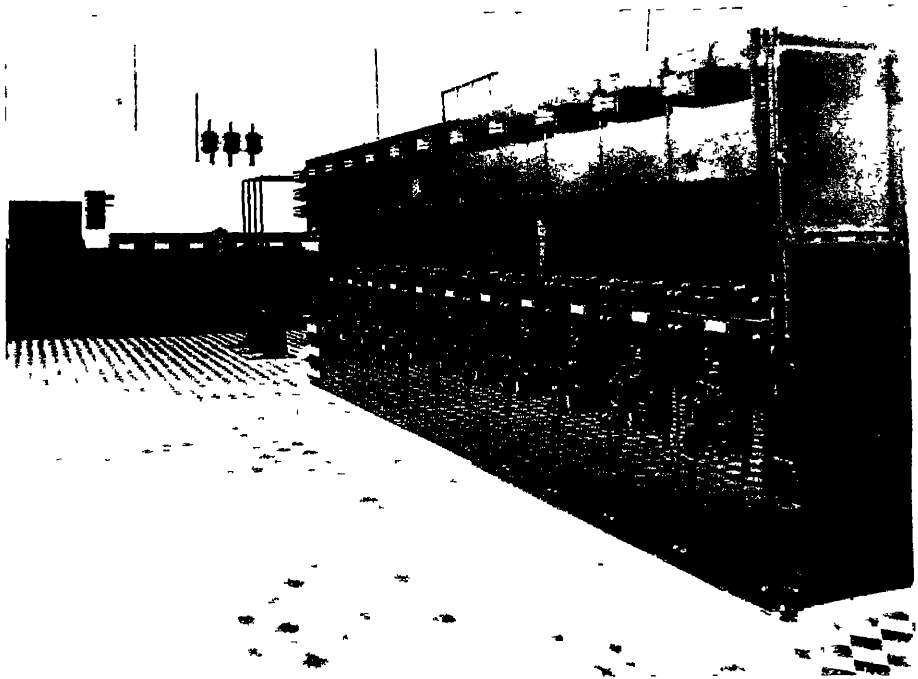


Fig 52 Front View of 440 Volts Three-phase Alternating Current Switchboard

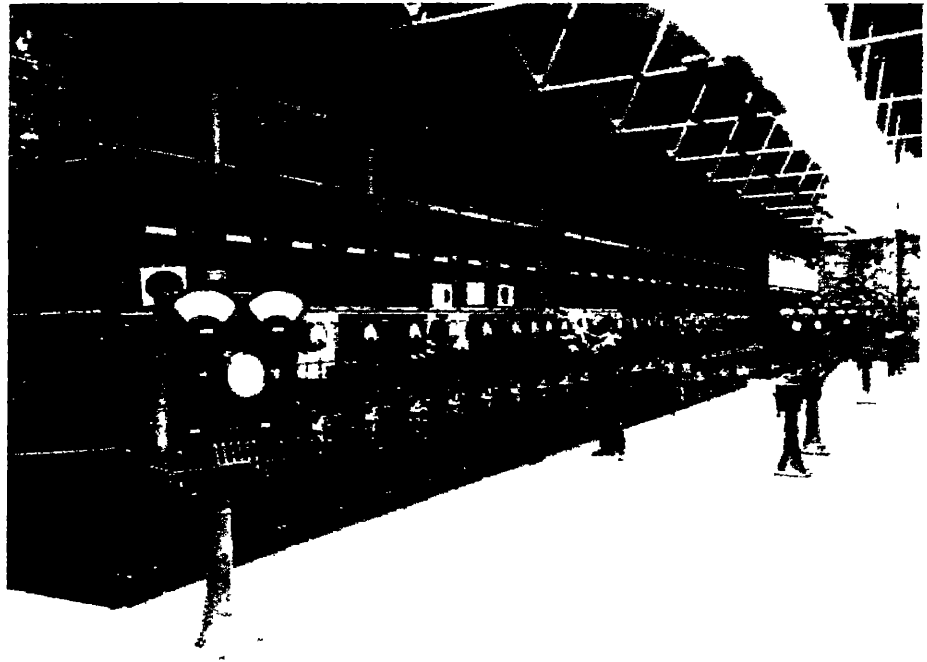


FIG 53 FRONT VIEW OF LOW TENSION ALTERNATING CURRENT SWITCHBOARD WITH BUSBAR ISOLATORS

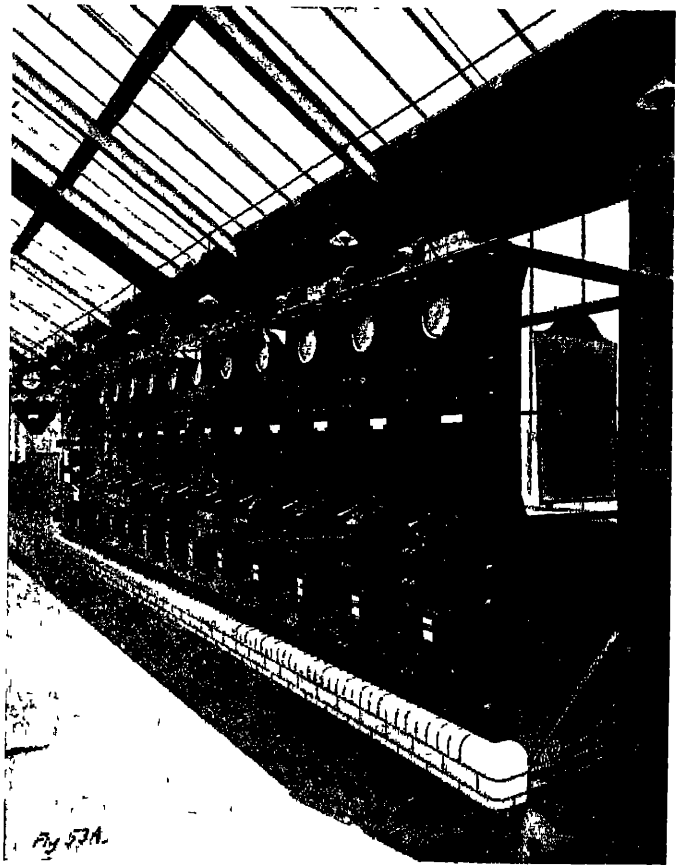


FIG 53A FRONT VIEW OF 400 VOLTS THREE-PHASE ALTERNATING CURRENT SWITCHBOARD

be fitted between the isolator and the breaker, and also between neighbouring panels, so that the oil circuit breaker, instrument transformers, wiring, etc , may be worked on in comparative safety

Fig 49 illustrates panels of this type.

For industrial and surface duty at collieries, conditions are such that open type switchboards are in many

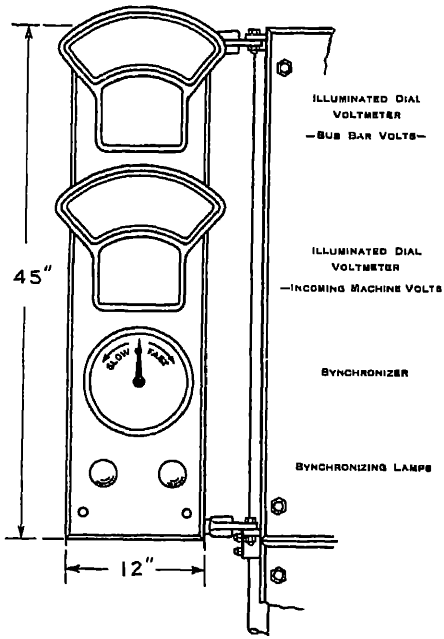


FIG 54 SYNCHRONIZING PANEL

cases unsuitable, and the switchgear apparatus is therefore mounted in sheet-iron and angle-iron cubicles

Fig 50 illustrates a panel of this type, and Fig 51 a similar panel but with externally operated and interlocked busbar isolating switches

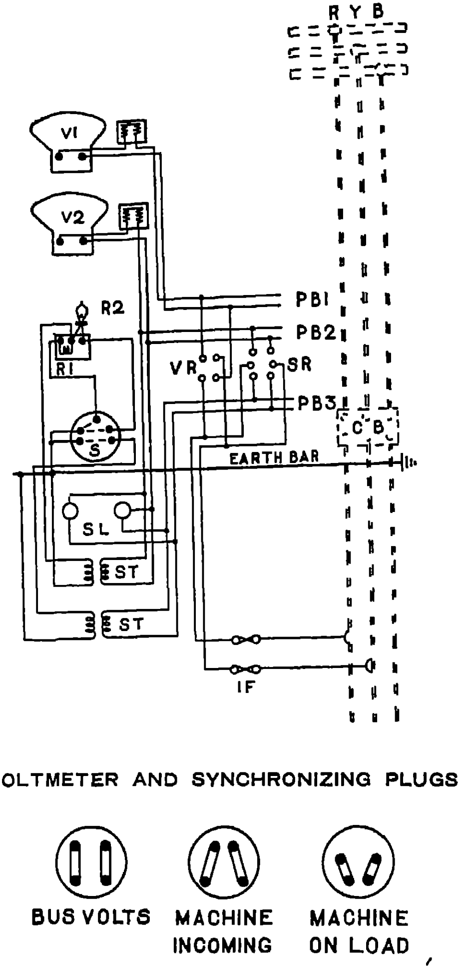
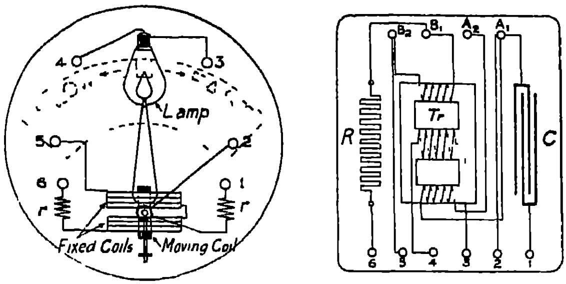
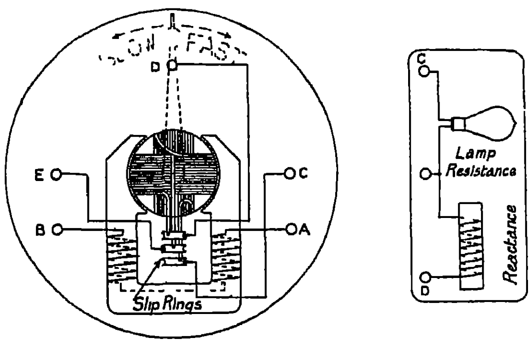


FIG 55 DIAGRAM OF SYNCHRONIZING CONNECTIONS



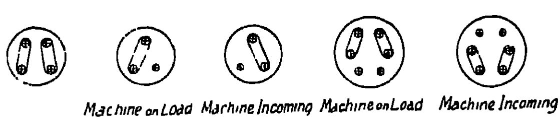
From "Power Wiring Diagrams" (Dover)

FIG 56 INTERNAL CONNECTIONS OF WESTON SYNCHROSCOPE AND AUXILIARY BOX



From "Power Wiring Diagrams" (Dover)

FIG 57 INTERNAL CONNECTIONS OF B T-H ROTARY FIELD SYNCHROSCOPE AND AUXILIARY (PHASE SPLITTING) BOX



From "Power Wiring Diagrams" (Dover)

FIG 58 CONNECTIONS OF THREE-, FOUR, AND SIX-POINT SYNCHRONIZING PLUGS

In the latter case the isolating switch and oil circuit breaker are interlocked as follows—

(*a*) The busbar isolating switch cannot be opened or closed on load

(*b*) Access to the oil circuit breaker compartment cannot be obtained unless the breaker is tripped and the busbar isolator in the open position

Such interlocks ensure a large degree of safety to the operator, who is enabled to carry out maintenance work without danger of accidental contact with bare conductors

Typical alternating current switchboards of the types described in the foregoing paragraphs are illustrated in Figs 52, 53, and 53A

Synchronizing. When generator circuits have to be synchronized an equipment of the type illustrated in Fig 54 is used

Potential receptacles are placed on each generator panel, and by means of suitable plugs the circuits are coupled to the synchronizing instruments

Figs 55–58 illustrate typical connections

Acknowledgment is given of the courtesy of the British Thomson-Houston Company, the Metropolitan-Vickers Company, Messrs Ferguson, Pailin, and the Artic Fuse Company, for information and illustrations supplied in the preparation of the foregoing

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END OF VOLUME III

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